UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

SEP 16 2016

OFFICE OF
AIR QUALITY PLANNING
AND STANDARDS

MEMORANDUM

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

FROM: Stephen D. Page, Director
Office of Air Quality Planning and Standards

TO: Regional Air Division Directors, Regions 1 – 10

The purpose of this memorandum is to distribute a non-binding guidance document titled, "Guidance on the Preparation of Exceptional Events Demonstrations for Wildfire Events that May Influence Ozone Concentrations."

The EPA Headquarters and EPA Regional offices collaborated in the development of this guidance to assist air agencies preparing exceptional events demonstrations for wildfire influences on ozone concentrations that meet the requirements of Clean Air Act section 319(b) and the Exceptional Events Rule signed on September 16, 2016, and posted on the EPA's Web site at *https://www.epa.gov/air-quality-analysis/treatment-data-influenced-exceptional-events*. This guidance document provides three different tiers of analyses that apply to the "clear causal relationship" criterion within an air agency's exceptional events demonstration. This document reflects input received from interested parties during the public comment period that closed on February 3, 2016.

Please distribute to air agencies in your Region. If you have any questions concerning this document, please contact Lev Gabrilovich at (919) 541-1496 or *gabrilovich.lev@epa.gov*.

Attachment

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

Final

September 2016

U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Air Quality Policy Division
Geographic Strategies Group
Research Triangle Park, North Carolina

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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	Nitric 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

Statutory and Regulatory Requirements

The Environmental Protection Agency (EPA) promulgated the Exceptional Events Rule 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 EPA revised the 2007 Exceptional Events Rule in 2016[2] based on implementation experiences with the exceptional events data exclusion process. The revised Exceptional Events Rule at 40 CFR 50.14(c)(3) clarifies that an exceptional events demonstration must include the following elements:

1) A narrative conceptual model that describes the event(s) causing the exceedance or violation and a discussion of how emissions from the event(s) led to the exceedance or violation at the affected monitor(s);
2) A demonstration that the event affected air quality in such a way that there exists a clear causal relationship between the specific event and the monitored exceedance or violation;
3) Analyses comparing the claimed event-influenced concentration(s) to concentrations at the same monitoring site at other times. The Administrator shall not require a State to prove a specific percentile point in the distribution of data;
4) A demonstration that the event was both not reasonably controllable and not reasonably preventable;
5) A demonstration that the event was caused by human activity that is unlikely to recur at a particular location or was a natural event; and
6) Documentation that the submitting air agency followed the public comment process

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) concentrations.[4] 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.

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[1] "Treatment of Data Influenced by Exceptional Events; Final Rule" (72 FR 13560, March 22, 2007).

[2] The EPA has prepared this guidance to align with the promulgated Exceptional Events Rule revisions signed on September 16, 2016, and available on the EPA's exceptional events website at *http://www2.epa.gov/air-quality-analysis/treatment-data-influenced-exceptional-events*.

[3] References to "air agencies" include state, local, and tribal air agencies responsible for implementing the Exceptional Events Rule. The regulatory text in the 2007 Exceptional Events Rule often uses "State" to apply to "air agencies." In the context of flagging data and preparing and submitting demonstrations, the role of and options available to air agencies may also apply to federal land managers of Class I areas and other federal agencies managing federal land.

[4] This guidance addresses wildfire events only, although many technical analyses described in Section 3 apply to both wildfire and prescribed fires. The EPA intends to include additional detail for demonstrations for prescribed fires on wildland in a future appendix to this guidance.

Purpose of this Document

The EPA developed this document to assist air agencies preparing exceptional events demonstrations for wildfire influences on O_3 concentrations that meet the requirements of CAA section 319(b) and the Exceptional Events Rule. This guidance document provides three different tiers of analyses that apply to the "clear causal relationship" criterion within an air agency's exceptional events demonstration.

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 Exceptional Events Rule 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 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. As a result, this guidance is expected to improve the EPA's efficiency in reviewing demonstrations prepared consistent with the guidance. While this guidance contains example analyses that air agencies may use in their demonstrations, air agencies can also prepare analyses or present documentation not listed or explained in this guidance provided the information is well-documented, appropriately-applied, technically sound, and supports the weight of evidence showing for the Exceptional Events Rule regulatory criteria.

The EPA acknowledges the complexity and intricacies of regional conditions prevalent across the country. The EPA is committed to continuing to provide clarification and assistance to states as the Exceptional Events Rule is implemented and through communications between the Regions and the States to ensure that these regional conditions are adequately addressed. Similarly, we intend to post new information and tools as they become available on the EPA's exceptional events website at *http://www2.epa.gov/air-quality-analysis/treatment-data-influenced-exceptional-events*.

Fire-related Definitions and Terminology

The Exceptional Events Rule at 40 CFR 50.1(n) defines a wildfire 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 developed into a wildfire. A wildfire that predominantly occurs on wildland is a natural event." The Exceptional Events Rule and this guidance document differentiate wildfires from prescribed fires in that a prescribed fire is "any fire intentionally ignited by management actions in accordance with applicable laws, policies, and regulations to meet specific land or resource management objectives." 40 CFR 50.1(m). An exceptional events demonstration must include a certification that a smoke management plan or basic smoke management practices was employed. The 2016 Exceptional Events Rule revisions also codified the following definition of wildland: "Wildland means an area in which human activity and development are essentially non-existent, except for roads, railroads, power lines, and similar transportation facilities. Structures, if any, are widely scattered." 40 CFR 50.1(o). 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(s) and its resulting emissions that affect air quality in such a way that there exists a clear causal relationship between the specific event(s) and the monitored exceedance(s) or violation(s), is not reasonably controllable or preventable, is an event(s) caused by human activity that is unlikely to recur at a particular location or a natural event(s), and is determined by the Administrator in accordance with 40 CFR 50.14 to be an exceptional event. It does not include air pollution relating to source noncompliance. Stagnation of air masses and meteorological inversions do not directly cause pollutant emissions and are not exceptional events. Meteorological events involving high temperatures or lack of precipitation (*i.e.*, severe, extreme or exceptional drought) also do not directly cause pollutant emissions and are not considered exceptional events. However, conditions involving high temperatures or lack of precipitation may promote occurrences of particular types of exceptional events, such as wildfires or high wind events, which do directly cause emissions. See promulgated definition at 40 CFR 50.1(j).
- *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

Each event submitted by an air agency under the Exceptional Events Rule must meet certain minimum criteria, as defined in the CAA and the implementing regulations. Some of the minimum criteria involve a technical analysis that must be tailored to the specific event so as to make the necessary demonstration. The EPA expects that the documentation and analyses that air agencies should include in their demonstrations will vary consistent with the event characteristics, the relationship to the monitor where the exceedance occurred, and the complexity of the airshed, among other points. The EPA reviews exceptional events demonstrations on a case-by-case basis using a weight of evidence approach considering the specifics of the individual event. This means the EPA considers all relevant evidence submitted with a demonstration or otherwise known to the EPA and qualitatively "weighs" this evidence based on its relevance to the Exceptional Events Rule criterion being addressed, the degree of certainty, the persuasiveness, and other considerations appropriate to the individual pollutant and the nature and type of event before acting to approve or disapprove an air agency's request to exclude data.

This guidance outlines a tiered approach for addressing the clear causal relationship element within a wildfire/ozone demonstration, recognizing that some wildfire events may be more clear and/or extreme and, therefore, require relatively less evidence to satisfy the rule requirements. Tier 1 clear causal analyses should be used for wildfire events that cause clear O_3 impacts in areas or during times of year that typically experience lower O_3 concentrations, and are thus simpler and less resource intensive than analyses for other events. Tier 2 clear causal analyses are likely appropriate when the impacts of the wildfire on O_3 levels are less clear and require more supportive documentation than Tier 1 analyses. Tier 3 clear causal analyses should be used for events in which the relationship between the wildfire and the O_3 exceedance or violation is more complicated than the relationship in a Tier 2 analysis, and thus would require more supportive documentation than Tier 2 analyses. Tier 1 analyses are described in detail in Section 3.4, Tier 2 analyses are described in Section 3.5, and Tier 3 analyses are described in Section 3.6.

The Exceptional Events Rule at 40 CFR 50.14(c)(2) requires an air agency to provide an "Initial Notification of Potential Exceptional Event" to the EPA Regional office after the air agency identifies a potential exceptional event. During this process, the EPA expects to discuss potential event-influenced exceedances with an affected air agency prior to the air agency preparing and submitting a demonstration. For wildfire events, this "initial notification" is expected to focus, in part, on observed ozone concentrations and how the wildfire event compares to the key factors discussed in Sections 3.4 through 3.6 of this guidance. As a result of this discussion, the EPA and the air agency will likely identify the appropriate tier (Tier 1, 2, or 3) for the event demonstration. Figure 1 shows a flowchart summarizing the overall process for preparing, submitting, and reviewing wildfire O_3 demonstrations, which includes the Initial Notification process and recommended review timelines.

Scope of This Guidance Document

Event types: This document focuses on the preparation of demonstrations for wildfires that cause monitored O_3 exceedances or violations. This document does not specifically address demonstration components that may be necessary for showing prescribed fire impacts on O_3 concentrations.[5] However, many example technical analyses contained in the "clear causal relationship" section of this document may also be appropriate for exceptional events demonstrations for prescribed fires that cause O_3 exceedances or violations. The "human activity unlikely to recur" and "not reasonably controllable or preventable" elements require different approaches for prescribed fires than those included in this guidance document because prescribed fires are "human activities" under the Exceptional Events Rule. This guidance describes the approach appropriate for wildfires, which are natural events.

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[5] The EPA is developing separate guidance on the preparation of demonstrations for prescribed fire impacts on O_3 concentrations.

Regulatory determinations: The Exceptional Events Rule clarifies that it applies to the treatment of data showing exceedances or violations for the following types of regulatory actions:

- An action to designate or redesignate an area as attainment, unclassifiable/ attainment, nonattainment or unclassifiable for a particular NAAQS. Such designations rely on a violation at a monitoring site in or near the area being designated;
- 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 regarding whether a nonattainment area has attained a NAAQS by its CAA deadline. This type of determination includes "clean data determinations;
- A determination that an area has data for the specific NAAQS, which qualify the area for an attainment date extension under the CAA provisions for the applicable pollutant;
- 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; and
- Other actions on a case-by-case basis if determined by the EPA to have regulatory significance based on discussions between the air agency and the EPA Regional office during the Initial Notification of Potential Exceptional Event process.

Outline of this Guidance

This guidance document is organized by Exceptional Events Rule-required elements in the recommended order for inclusion within an exceptional events demonstration. Section 2 covers the narrative conceptual model, Sections 3 through 5 discuss the Exceptional Events Rule criteria, and Section 6 addresses the public comment process. Of particular note, Sections 3.4 – 3.6 discuss the three tiers of analyses to address the clear causal relationship criterion.

Role of this Guidance

The Exceptional Events Rule contains the regulatory requirements for exceptional events and exceptional events demonstrations. This document provides guidance and applies the rule criteria to the development of demonstrations for wildfire events that cause monitored ozone exceedances or violations. 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,[6] the EPA will also prepare documentation to support the decision. The Exceptional Events Rule and the preamble to the rule contain additional detail regarding those entities authorized to submit demonstrations; the timing for demonstration preparation, submittal and review; the communications process between air agencies and the reviewing EPA Regional office; regional consistency; dispute resolution; and other concepts or rule provisions that apply generally to demonstrations for event types and pollutant combinations that are not the specific focus of this wildfire/ozone guidance.

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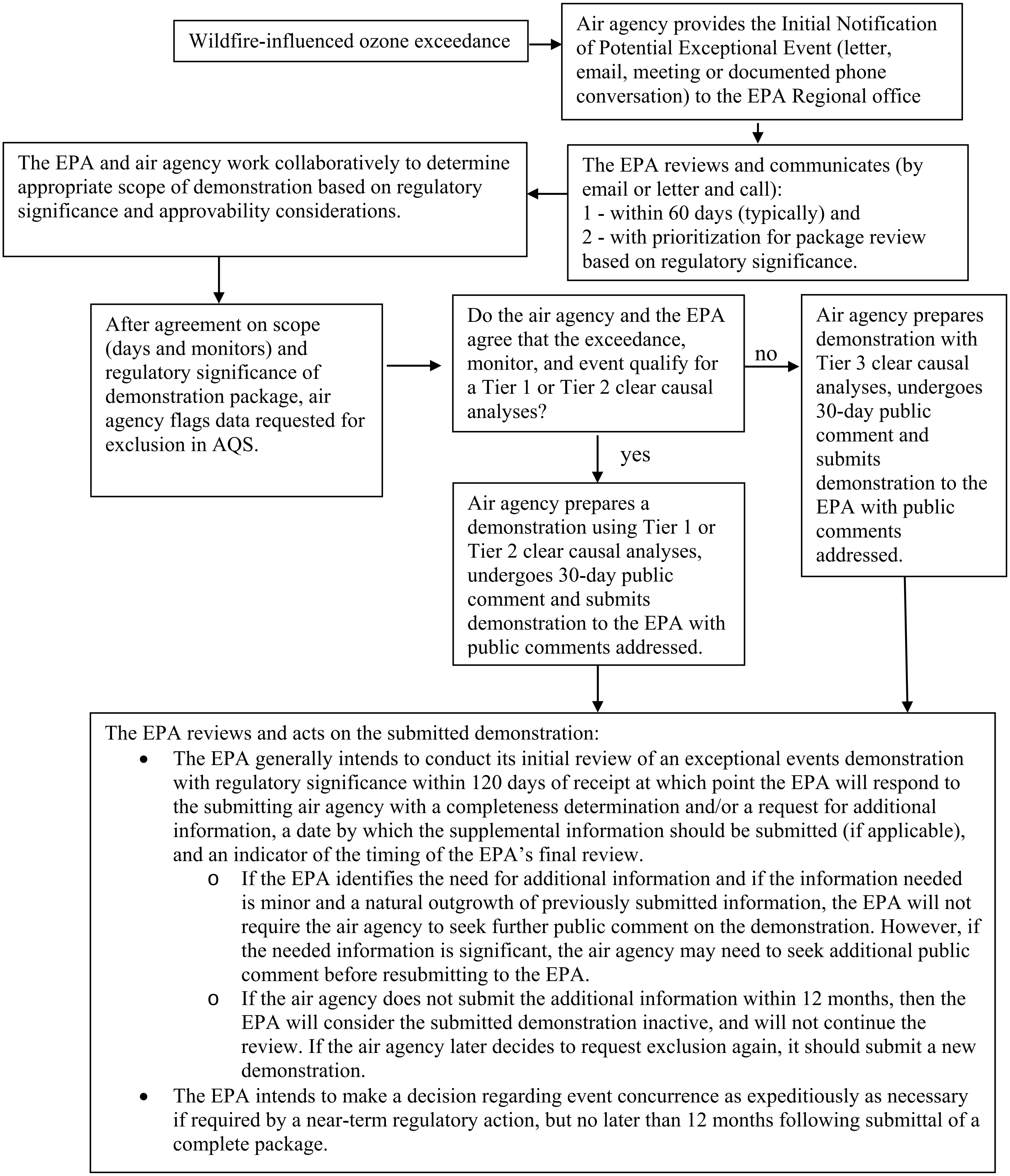
[6] Submission of a demonstration containing technical analyses consistent with the guidance does not automatically ensure the EPA's approval. The EPA will review each request under the Exceptional Events Rule on a case-by-case basis using a weight of evidence approach.

Figure 1: Flowchart for the recommended process for air agencies' preparation, submission, and review of exceptional events demonstrations for wildfire influences on O_3, including communications with EPA Regional offices.



Wildfire-influenced ozone exceedance

Air agency provides the Initial Notification of Potential Exceptional Event (letter, email, meeting or documented phone conversation) to the EPA Regional office

The EPA reviews and communicates (by email or letter and call):
1 - within 60 days (typically) and
2 - with prioritization for package review based on regulatory significance.

The EPA and air agency work collaboratively to determine appropriate scope of demonstration based on regulatory significance and approvability considerations.

After agreement on scope (days and monitors) and regulatory significance of demonstration package, air agency flags data requested for exclusion in AQS.

Do the air agency and the EPA agree that the exceedance, monitor, and event qualify for a Tier 1 or Tier 2 clear causal analyses?

Air agency prepares demonstration with Tier 3 clear causal analyses, undergoes 30-day public comment and submits demonstration to the EPA with public comments addressed.

Air agency prepares a demonstration using Tier 1 or Tier 2 clear causal analyses, undergoes 30-day public comment and submits demonstration to the EPA with public comments addressed.

The EPA reviews and acts on the submitted demonstration:

- The EPA generally intends to conduct its initial review of an exceptional events demonstration with regulatory significance within 120 days of receipt at which point the EPA will respond to the submitting air agency with a completeness determination and/or a request for additional information, a date by which the supplemental information should be submitted (if applicable), and an indicator of the timing of the EPA's final review.
    - If the EPA identifies the need for additional information and if the information needed is minor and a natural outgrowth of previously submitted information, the EPA will not require the air agency to seek further public comment on the demonstration. However, if the needed information is significant, the air agency may need to seek additional public comment before resubmitting to the EPA.
    - If the air agency does not submit the additional information within 12 months, then the EPA will consider the submitted demonstration inactive, and will not continue the review. If the air agency later decides to request exclusion again, it should submit a new demonstration.
- The EPA intends to make a decision regarding event concurrence as expeditiously as necessary if required by a near-term regulatory action, but no later than 12 months following submittal of a complete package.

2. Conceptual Model of Event

2.1 Overview and Exceptional Events Rule Provisions

The Exceptional Events Rule at 40 CFR 50.14(c)(3)(iv)(A) requires that demonstrations include a narrative conceptual model describing the event. This narrative conceptual model should also discuss the interaction of emissions, meteorology, and chemistry of event and non-event O_3 formation in the area, and, under 40 CFR 50.14(c)(3)(i), must describe the regulatory significance of the proposed data exclusion. Because this narrative should appear at or near the beginning of a demonstration, it will help readers and the reviewing EPA Regional office understand the event formation and the event's influence on monitored pollutant concentrations before the reader reaches the portion of the demonstration that contains the technical evidence to support the requested data exclusion. The EPA expects that much of the information the air agency discussed with or submitted to the EPA during the Initial Notification process would also be useful in the narrative conceptual model section of a demonstration.

2.2 Examples of Supporting Documentation

The following sections describe the possible types of monitored evidence and technical analyses that air agencies should include in their demonstration. To be meaningful and clearly interpreted, air agencies should tie these analyses to a simple narrative describing how emissions from a specific wildfire (or group of fires) caused O_3 exceedances or violations at a particular location and how these event-related emissions and resulting exceedances or violations 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 wildfire 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 several 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 the monitored exceedances or violations. 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 causing elevated O_3 concentrations (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.

To promote a shared understanding and interpretation of this information, the EPA recommends that air agencies include the following information in the narrative conceptual model to the extent available:

- 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 wildfire(s) believed by the air agency to have caused the exceedance, not just a list of wildfires occurring within the jurisdiction of the submitting air agency.[7]
- 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.
- A brief explanation and identification of the cause and point of origin for the event wildfire(s) (to the extent known).
- Examples of media coverage of the event, including special weather statements, advisories, and news reports.
- Smoke forecasts based on meteorology and burn conditions (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 wildfire emissions.
- Description of the route of the wildfire emissions to the influenced monitor, including meteorological information (*e.g.*, general atmospheric circulation characteristics) regarding the transport of wildfire emissions to the monitor.
- 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.

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[7] 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.*

- Description of the regulatory determination anticipated to be influenced 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 State Implementation Plan (SIP) status.

3. Clear Causal Relationship between the Specific Event and the Monitored Concentration

3.1 Overview and Exceptional Events Rule Provisions

The Exceptional Events Rule requires 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.[8] 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, air agencies should further support the clear causal relationship criterion by demonstrating that the wildfire's emissions were transported to the monitor, that the emissions from the wildfire influenced the monitored concentrations, and, in some cases, quantifying the contribution of the wildfire's emissions to the monitored O_3 exceedance or violation. Table 1 summarizes the tiered analyses for the clear causal relationship criterion.

Table 1. Summary of Tiered Analyses.

Tier 1: Section 3.4	Tier 2: Section 3.5	Tier 3: Section 3.6
Wildfires that clearly influence monitored O_3 exceedances or violations when they occur in an area that typically experiences lower O_3 concentrations. This tier is 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.	The wildfire event's O_3 influences are higher than non-event related concentrations, and fire emissions compared to the fire's distance from the affected monitor indicate a clear causal relationship.	The wildfire does not fall into the specific scenarios that qualify for Tier 1 or Tier 2, but the clear causal relationship criterion can still be satisfied by a weight of evidence showing.

3.2 Event-related Concentration in the Context of Historical Concentrations

As noted above, part of demonstrating a clear causal relationship between the event and the monitored O_3 exceedance involves comparing the event-related exceedance with historical concentrations measured at the affected monitor or at other monitors in the area during the same season. Air agencies should compare the data requested for exclusion with the historical

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[8] *See* 40 CFR 50.14(c)(3)(iv)(B)-(C).

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 wildfire caused the monitored exceedance or violation, such as a list of previous wildfire dates and locations, evidence of stratospheric intrusion, or evidence supporting other event types. In addition to showing how the level of the event exceedance compares with historical data, air agencies can also show how the diurnal or seasonal pattern differs, if such a deviation occurred, due to the event. Effective statistical summaries that 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 influenced 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, these comparisons to historical concentrations may inform whether additional evidence is needed to successfully establish the clear causal relationship element. For example, historical comparisons conclusively showing that the event-influenced 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 the appropriateness of Tier 1 (Section 3.4) analyses for the clear causal relationship criterion. Additionally, air agencies may be able to use the percentile ranking of the event-influenced data against historical data to determine whether a Tier 2 analysis (Section 3.5) is appropriate.

3.2.1 Examples of Supporting Documentation

- Plot the maximum daily 8-hour O_3 concentrations at the affected monitor(s) for the high O_3 seasons (April through October, or other months as appropriate) for at least 5 years. Figure 2 provides an example of this approach. Alternatively, including separate plots for each year (or season) may also be an informative approach to presenting this information.
- Show time series plots of O_3 concentrations at nearby monitors 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 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.
- Show a time series plot covering 12 months (or the months of the high O_3 season) overlaying all 5 years of data plotted to identify 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.

- Discuss trends due to emission reductions from planning efforts, or other variability due to meteorology or economics of an area, to explain 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-influenced monitor to include in a demonstration.

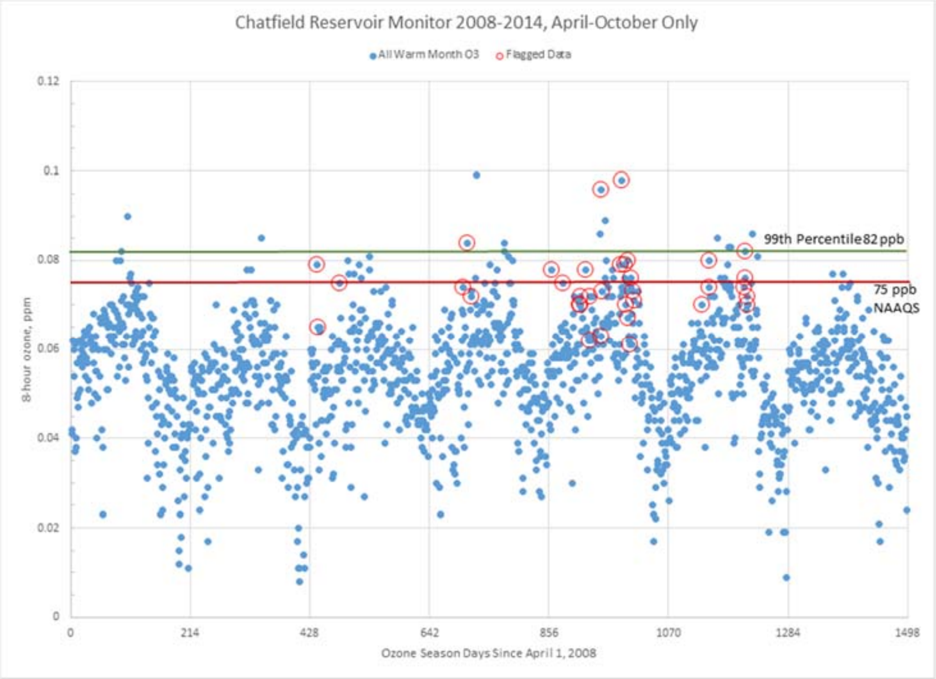
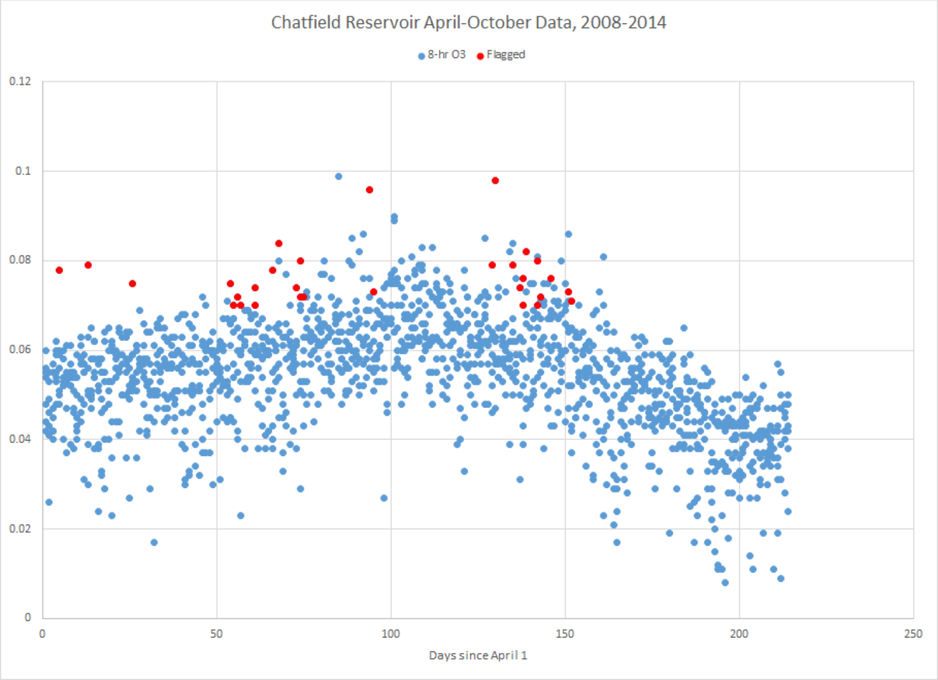


Figure 3. Example of a seasonal O_3 plot, overlaying multiple years of data from an event-influenced monitor to include in a demonstration.



3.3 Concept of Different Tiers of Exceptional Events Demonstrations

The nature and severity of a wildfire 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. The tiered strategy described in this guidance contains three tiers of analyses for the clear causal relationship criterion and is based on an event's potential relationship to 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 wildfire 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.

Events with the clearest clear causal relationship between the event and monitored O_3 concentrations may find that Tier 1 analyses are appropriate. Tier 1 analyses for the clear causal relationship are likely appropriate for 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 analyses would likely need the least amount of evidence. Tier 2 analyses should include more evidence than Tier 1 analyses to show a clear causal relationship and should be used in situations with less clear wildfire impacts. Tier 3 analyses are appropriate when the relationship between the wildfire and the monitored O_3 exceedances or violations is more complex. Section 3.4 discusses Tier 1 analyses, Section 3.5 discusses Tier 2 analyses and Section 3.6 discusses Tier 3 analyses.

The three analytical tiers described in this guidance are intended to assist air agencies in determining the appropriate analyses to include in an exceptional events submission. Air agencies are encouraged to provide sufficient information to support the request, and where an event is “close” to the cut-point for a particular tier, the air agency may choose to employ the more complex analysis in order to ensure the submittal includes the appropriate level of information to support the exceptional events demonstration.

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

The EPA expects that Tier 1 analyses supporting the clear causal relationship criterion may be appropriate for wildfires that clearly influence monitored O_3 exceedances or violations when they occur in an area that typically experiences lower O_3 concentrations (*e.g.*, few or no O_3 exceedances/violations), 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” wildfire events could employ Tier 1 analyses. In these situations, O_3 impacts should be accompanied by clear evidence that the wildfire’s emissions were transported to the location of the monitor.

3.4.1 Evidence the Event, Monitor(s), and Exceedance Meet the Key Factor for Tier 1 Clear Causal Analyses

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 analyses 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 clearly attributable to a wildfire 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 wildfire-related exceedance, for example during the normal O_3 season, they either should also be attributable to wildfire (or other exceptional events) or if attributable to normal emissions and photochemistry, they should be clearly lower in magnitude than the wildfire-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 occurring during the same timeframe as 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, either of which an air agency can provide for this section of the demonstration.

1) Provide a time series plot covering 12 months (or the typical O_3 season months plus months with the event-related exceedance) overlaying at least 5 years or the length of time data are available if less than 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 wildfire-related exceedance are not attributable to normal emissions and photochemistry, are attributable to wildfire (or other exceptional events), or are clearly lower in magnitude than the wildfire-related concentrations.

3.4.2 Evidence that the Wildfire 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 clear causal analysis that the emissions from the wildfire 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 include:

- *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 wildfire 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 satellite imagery, plume imagery alone does not conclusively show that wildfire emissions transported aloft reached a ground-level monitor. If plume arrival at a given location coincides with elevation of wildfire 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 from the event location to the monitor with the elevated O_3 concentration.

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

If a wildfire 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 should not use Tier 1 analyses. The air agency should then determine whether Tier 2 analyses or Tier 3 analyses would be appropriate. To identify key factors that could differentiate whether Tier 3 analyses or Tier 2 analyses are appropriate, the EPA reviewed previously approved exceptional events demonstrations, conducted a literature review of case specific fire-O_3 impacts, and completed photochemical modeling analyses. Section 3.6 discusses Tier 3 analyses. This section of the guidance discusses the EPA's methodology for determining the key factors of a Tier 2 analysis. 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. 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 concentrations 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 exceptional events 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. In 2011, 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. In 2012, the EPA concurred with the exclusion of eight 8-hour daily maximum O_3 exceedances during April 2011 in Kansas caused by wildfires and prescribed fires.

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).[9] 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 clear causal analysis. 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 Clear Causal Analyses

This section details the evidence to be included in a Tier 2 analysis 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 analysis provides sufficient evidence to satisfy the clear causal relationship criteria for wildfire O_3 demonstrations. To determine an appropriate and conservative value for the Q/D threshold (below which the EPA recommends

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[9] The 2011 NEI is the most current publicly available version of the EPA's National Emissions Inventory at the time of development of this guidance. We used the NEI rather than other emissions sources because it is nationally consistent, quality-assured, and an inventory that is reviewed by state, local, and tribal air agencies and represents a comprehensive and detailed estimate of air emissions of criteria pollutants, criteria precursors, and hazardous air pollutants from air emissions sources. The EPA compiles the inventory from data provided by state, local and, tribal air agencies for sources in their jurisdictions and then supplements these data with additional information developed by the EPA.

Tier 3 analyses for the clear causal relationship), 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 Tier 2 analyses for the clear causal relationship criterion are likely 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 wildfire 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 if the 1st hour occurred at 9 p.m.

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. The reported latitude and longitude of the fire from inventories is generally the centroid of the fire parcel. However, air agencies are not limited to calculating distance based on the centroid of the fire parcel, provided the latitude/longitude calculation is well-documented and supported.

5) For each fire and each day, identify the sum of NOx and reactive VOC (rVOC) emissions in tons/day. If only total organic gas (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).[10] 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.[11] 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 Federal Information Processing Standard (FIPS) code, 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 the EPA's Clearinghouse for Inventories and Emissions Factors (CHIEF) at *https://www.epa.gov/chief*. 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

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[10] rVOC is defined for the purposes of estimating wildland fire impacts as part of a screening level demonstration as the sum of all VOC species excluding methane and those mapped to "nonreactive" or "unknown" when applying the most up-to-date VOC speciation profile to total organic gases. VOC speciation profiles are available online as part of EPA's SPECIATE database at *https://www3.epa.gov/ttnchie1/software/speciate/*.

[11] An official version of the NEI is generally publicly available within 18 months of the end of the NEI year. States, however, have 1 year to compile and submit inventory data at the end of an NEI year. In some cases, official NEI data may not be available for use in an air agency demonstration, either because of the time lag between the end of the inventory year and NEI availability or because the fire did not happen in a NEI year. In these scenarios, air agencies may use any other well-documented and well-supported source of emissions and activity data.

(*http://www.airfire.org/smartfire/*). Air agencies can use sources other than the EPA's NEI for their fire emissions and activity data as part of an exceptional events demonstration if the air agency believes that another source of information more accurately characterizes the event and its resulting emissions. Any additional source of emissions and activity data must be 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 should be well-documented and supported. 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 $Q/D \geq 100$ for any of the days. If yes, evaluate key factor #2. If $Q/D < 100$, then the air agency should consider the fires in aggregate, or use Tier 3 analyses to support the clear causal relationship criterion.

7) If any of the individual fires do not have $Q/D \geq 100$, 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.

   For situations where only one fire parcel is thought to affect a monitored ozone concentration:
   The distance between the latitude and longitude of the monitor and the latitude and longitude of the fire (accounting for the curvature of the Earth) should be used. The reported latitude and longitude of the fire from inventories is generally the centroid of the fire parcel. However, air agencies are not limited to calculating distance based on the centroid of the fire parcel, provided the latitude/longitude calculation is well-documented and supported.

   For situations where multiple fires are thought to contribute to a monitored ozone concentration:
   The distance (D) between the "fire" and monitor should be determined using an emissions weighted average distance between the fire and the monitor.

For example 1, if two fire parcels A1 and B1 are found to contribute to an O_3 concentration on a given day, find the locations and emissions (sum of NOx and VOC) for each fire parcel. If parcel A1 is the closer fire, at 100 km from the monitor and has relatively low emissions such as 1,000 tons while parcel B1 is further from the monitor at 200 km and has larger emissions such as 10,000 tons, then the air agency should calculate the emissions weighted distance as emissions A1 times distance A1 plus emissions B1 times distance B1. Then this weighted sum is divided by the sum of the emissions A1 and B1. Or, filling in the numbers, 100*1,000 + 200*10,000 divided by 11,000. The emissions weighted distance would then be 190.9 km, and the Q/D would be 11,000/190.9 or 57.6 tons/km. Applying this approach indicates that the weighted distance would be closer in magnitude to the fire with the larger emissions (*i.e.*, Fire B1), but slightly smaller than the actual distance to Fire B1 because of the contribution from the closer, smaller fire.

For example 2 (involving Fires A2, B2, and C2), if an air agency determines that 3 fires contribute to the O_3 exceedance or violation, the distance between the center of fire parcel and the monitor would be calculated as follows:

$$emissions\ weighted\ average\ distance = \frac{(D_{A2}Q_{A2}) + (D_{B2}Q_{B2}) + (D_{C2}D_{C2})}{Q_{A2} + Q_{B2} + Q_{C2}}$$

Example 1:

	Distance between center of fire parcel and monitor (km)	Sum of NOx and VOC emissions on day being investigated	Emissions weighted distance between the fire and monitor	Q/D
Fire A1	100 km	1,000 tons	9.09	
Fire B1	200 km	10,000 tons	181.8	
		11,000 tons	190.9	57.6 tons/km

Example 2:

	Distance between center of fire parcel and monitor (km)	Sum of NOx and VOC emissions on day being investigated	Weighted distance between the	Q/D
Fire A2	100 km	10,000 tons	62.5	
Fire B2	150 km	5,000 tons	46.88	
Fire C2	50 km	1,000 tons	3.125	
		16,000 tons	112.5	142.2 tons/km

8) If the aggregate approach results in a $Q/D \geq 100$ for the day, evaluate key factor #2. Apply the same aggregated approach for the other identified days. If Q/D under the aggregate approach is < 100, then the air agency would follow Tier 3 analyses for the clear causal relationship criterion. The demonstration should show all calculations and values and 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. The EPA acknowledges that some exceedances may be caused by many small fires that when aggregated do not result in a $Q/D \geq 100$ for the day. When combined with satisfactory corroborating information, it is possible that aggregated wildfires with a Q/D less than 100 could result in an approved demonstration (following Tier 3 analyses). This corroborating information is described in Section 3.6 of this guidance.

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 clear causal analysis 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 99th 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 Exceptional Events Rule, 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 analysis to events in the 99th or higher percentile of 5 years of monitoring data will generally ensure the event-influenced 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 Exceptional Events Rule. 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 Exceptional Events Rule, if any), the key factor would be met. If both key factors (#1 and #2) are met, then a Tier 2 demonstration will likely 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 99th (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 analysis to support the clear causal relationship criterion. If the data are not in the 99th (or higher) percentile and are one of the top four O_3 maximums within 1 year, or if the EPA Regional office identified that a more complex analysis is needed, then the air agency should prepare a Tier 3 analysis for the clear causal relationship criterion.

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 wildfire affected the monitored O_3 concentration. Air agencies can use the following example evidence to demonstrate the wildfire emissions were present at the altitude of the monitor(s).

This evidence could include any of the following:

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

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

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

While fires typically 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). Air agencies can use evidence from regulatory and non-regulatory (*e.g.*, special purpose, emergency) monitors to support these analyses.

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

- Satellite evidence of smoke or precursors (NOx) at the monitoring site. *https://www.epa.gov/hesc/remote-sensing-information-gateway* and *http://arset.gsfc.nasa.gov/airquality/applications/fires-and-smoke* may be helpful resources.

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

- 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 wildfire's emissions influenced 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 wildfire 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 wildfire 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 wildfire 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 prescribed 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 wildfire 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. Forward-trajectories from specific wildfire events to specific monitors can also be used to indicate *potential* receptors. For purposes of assessing wildfire exceptional events, 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 satellite imagery, plume imagery alone does not conclusively show that wildfire emissions transported aloft reached a ground-level monitor. If plume arrival at a given location coincides with elevation of wildfire plume components (such as ground level measurements of $PM_{2.5}$, CO or organic and elemental carbon), those two pieces of evidence combined can show that smoke was transported from the event location to the monitor with the elevated O_3 concentration.

3.5.4 Summary of Evidence that Could be Used to Meet the Exceptional Events Rule 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 Analyses Should Include	**Tier 2 Analyses 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):	Evidence of transport of fire emissions from fire to the monitor (**one** of these):

• Trajectories linking fire with the monitor (forward and backward), considering height of trajectories • Satellite evidence in combination with surface measurements	• Trajectories linking fire with the monitor (forward and backward), considering height of trajectories • Satellite evidence in combination with surface measurements
	Evidence that the fire emissions affected the monitor (**one** of these): • Visibility impacts (satellite or photo) • Changes in supporting ground level measurements • Satellite NOx enhancements • Differences in spatial/temporal patterns

3.6 Tier 3 Analyses to Support the Clear Causal Relationship

Although the EPA has identified specific wildfire/O_3 scenarios that are appropriate for either Tier 1 or Tier 2 analyses to demonstrate the clear causal relationship criterion, and we have identified analyses and key factors associated with these tiers based on generally available data, we do not intend to imply that demonstrations for <u>all</u> other wildfire/O_3 events must include more analyses with increasing complexity.[12] Rather, this guidance is intended to indicate that if a wildfire/ozone event satisfies the key factors for either Tier 1 or Tier 2 clear causal analyses, then those analyses are the only analyses required to support the clear causal relationship criterion within an air agency's demonstration for that particular event. Other wildfire/O_3 events will be considered based on Tier 3 analyses, but some Tier 3 clear causal analyses may also be relatively straightforward and/or established with limited evidence. For example, a wildfire event may cause an exceedance during an area's photochemical O_3 season that is the fifth highest concentration in a year and falls within the 98th percentile of the 5-year distribution. Because the event occurs during the time of year as typically high O_3 concentrations, it would not qualify for Tier 1 analyses. Similarly, because the concentration in question is the fifth (versus fourth) high value and falls within the 98th (versus 99th) percentile, the event would also not qualify for Tier 2 analyses. However, when addressing the (Tier 3) clear causal relationship criterion within its demonstration, the affected air agency might complete a comparison to historical concentrations (required for all event/pollutant combinations under 40 CFR 50.14(c)(3)(iv)(C)), prepare backward and forward trajectories from the wildfire to the affected monitor, submit satellite imagery showing the smoke plume over the affected monitor, and submit a vertical ozone profile or model simulations. Together this information might satisfy the clear causal relationship criterion under a weight of evidence approach. Other, more complicated relationships between

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[12] In developing the tiering approach, the EPA intended to base the key factors within Tier 1 and Tier 2 on data or information that is generally available and accessible to all air agencies. We recognize that other information may be equally (or more) convincing and carry more "weight" under a weight of evidence assessment, but these data and/or tools may not be as widely available. As noted in this guidance, it is not our intent to prevent air agencies from using any relevant, well-documented, appropriately-applied and technically sound evidence.

the wildfires and influenced O_3 concentrations may require additional detail to satisfy the clear causal relationship element.

Regardless, as indicated in the example above, the EPA anticipates that air agencies can build upon the Tier 1 or Tier 2 analyses with the analyses described in this section (or other appropriate analyses/tools). The EPA does not expect an air agency to prepare all identified analyses but only those that add to their weight of evidence supporting the clear causal relationship. As with all exceptional events demonstrations, the submitting air agency and the EPA Regional office should discuss the appropriate level of evidence during the Initial Notification process.

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

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 to support Tier 3 analyses.

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

Because the relationship between the wildfire-related emissions and the monitored exceedance or violation cannot clearly be shown using Tier 1 or Tier 2 analyses, air agencies will need additional evidence to support the clear causal relationship criterion and show that the wildfire emissions affected the monitor. The Tier 3 clear causal relationship analyses could include multiple analyses from those examples listed in Section 3.6.4. 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 show that the emissions from the wildfire were clearly transported to the monitor. This will likely require a trajectory analysis or the satellite plume analysis described in 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), could 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 further support the clear causal relationship between the wildfire and the O_3 exceedance with matching day analyses, statistical regression models, or photochemical models, all of which are described in more detail below.

- 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 influenced 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 *See* e.g., 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, weekday versus weekend mismatches, and other days with unusual emissions). In a recently submitted demonstration,[13] 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. Although this demonstration preceded issuance of the instant guidance, the methods may be useful for air agencies conducting Tier III analyses.

- Statistical Regression Modeling
  Air agencies can use O_3 predictions from regression equations to assess the wildfire'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

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

by event-related emissions (*e.g.*, emissions from wildfires) 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 95th percentile of those positive 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 5th 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. *See*, e.g., Camalier et al., 2007; STI, 2014.

- Photochemical modeling
  This section describes the air quality modeling tools best suited for estimating wildfire 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, described as the difference between a model simulation with all sources and a subsequent model simulation where the wildfire(s) being quantified for impact are removed) 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 wildfire 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 wildfire 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 wildfire event and the monitored O_3 exceedance or violation. In summarizing the clear causal relationship section of their demonstration, the air agency should conclude with this type of statement, which states how the demonstration should meet the relevant statutory and regulatory criteria:

"On [day/time] an [event type] occurred that generated pollutant X or its precursors resulting in elevated concentrations at [monitoring location(s)]. The monitored [pollutant] concentrations of [ZZ] were [describe the comparison to historical concentrations including the percentile rank over an annual (seasonal) basis]. Meteorological conditions were not consistent with historically high concentrations, etc." and "The comparisons and analyses, provided in [section X] of this demonstration support Agency A's position that the wildfire 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 on [dates/time of data requested for exclusion, or reference to summary table in demonstration] and thus satisfies the clear causal relationship criterion."

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

4.1 Overview and Exceptional Events Rule Provisions

According to the CAA and the Exceptional Events Rule, 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 Exceptional Events Rule is: "…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 developed into a wildfire. A wildfire that predominantly occurs on wildland is a natural event." Prescribed fires can be treated as wildfires for purposes of identifying the applicable demonstration requirements under the Exceptional Events Rule 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.”).[14] 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 Exceptional Events Rule. Since wildfires on wildland are treated as natural events, 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.

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 Exceptional Events Rule 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 [as documented in X, or because…] 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 develops into a wildfire, then the air agency should supplement the language above with additional detail as to the conditions, which led to this evolution. For example, the air agency should indicate that the prescribed fire escaped secure containment lines and required suppression along all or part of its boundary or that 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 Exceptional Events Rule Provisions

According to the CAA and the Exceptional Events Rule, an exceptional event must be “not reasonably controllable or preventable.” The preamble to the Exceptional Events Rule 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

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[14] 40 CFR 50.1(o).

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 developed into 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. In showing that a prescribed fire has developed into a wildfire, air agencies should include the following documentation in their demonstrations: (1) news reports or notifications to the public characterizing the nature of the fire and (2) the demonstration submitters' explanation of the origin and evolution of the fire.

5.2 Examples of Supporting Documentation

The Exceptional Events Rule accepts that wildfire events on wildland are not generally reasonable to control or prevent. Therefore, a statement that the wildfire event was caused by one of the causes identified in the definition of wildfire (such as lightning), and thus by the terms of the Exceptional Events Rule, was not reasonably controllable or preventable, should satisfy this rule element. A report based on information from other agencies or from news reports may potentially be sufficient for this statement. The air agencies should work with their EPA Regional offices to ensure that their statements about the causes of the wildfire events are sufficient.

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 Exceptional Events Rule Provisions

According to the provisions in 40 CFR 50.14(c)(1)(i), air agencies must "notify the public promptly whenever an event occurs or is reasonably anticipated to occur which may result in the exceedance of an applicable air quality standard." In addition, according to 40 CFR 50.14(c)(3)(v), air agencies must "document [in their exceptional events demonstration] that the [air agency] followed the public comment process and that the comment period was open for a minimum of 30 days…." Further, air agencies must submit any received public comments to the EPA and address in their submission those comments disputing or contradicting the factual evidence in the demonstration. Air agencies with recurring events may also be subject to the mitigation requirements at 40 CFR 51.930. Air agencies subject to these requirements have additional obligations regarding public notification and engagement.

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, Web site postings, and/or places (library, agency office) where the hardcopy was available. As noted in Section 6.1, the agency should also include comments received and the agency's responses to those comments.

6.3 Example Conclusion Statement

In addition to the supporting information suggested in Section 6.2, the air agency should include a conclusion statement similar to the language below to demonstrate that it followed the public comment process.

"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), prior to promulgation of the Exceptional Events Rule revisions, 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 surrounding 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 that 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 that 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.[15] 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.

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

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[15] 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).

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 relationship 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

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-Influenced O_3 Exceptional Events Demonstrations

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. Additional information regarding these submissions is provided in Section 3.5 of this document. 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 Exceptional Events Rule 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 and 2011 NEIs (*https://www.epa.gov/air-emissions-inventories/national-emissions-inventory*) 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).[16]

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 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 NO_x 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.

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[16] 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/*.

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.

For the modeling studies of wildfire impacts on O_3, 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 25th-75th 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 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.

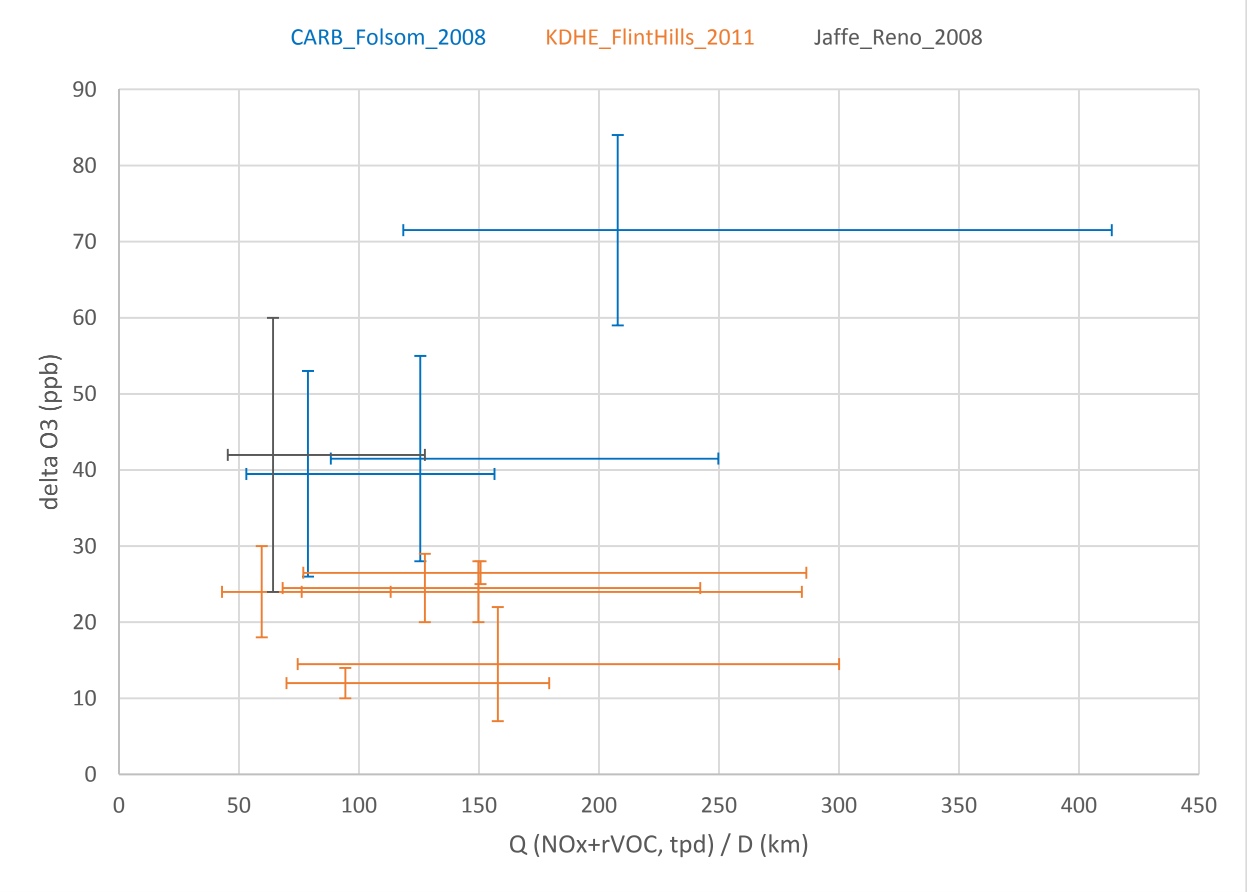


Figure A2-2. Event maximum 1-hour O_3 (ppb) impacts (left panels). The percent contribution from fire event NO_X emissions to event maximum 1-hour O_3 impacts shown at right. The percent contribution plots show that both NO_X and VOC emissions from fires can contribute to downwind O_3 formation.

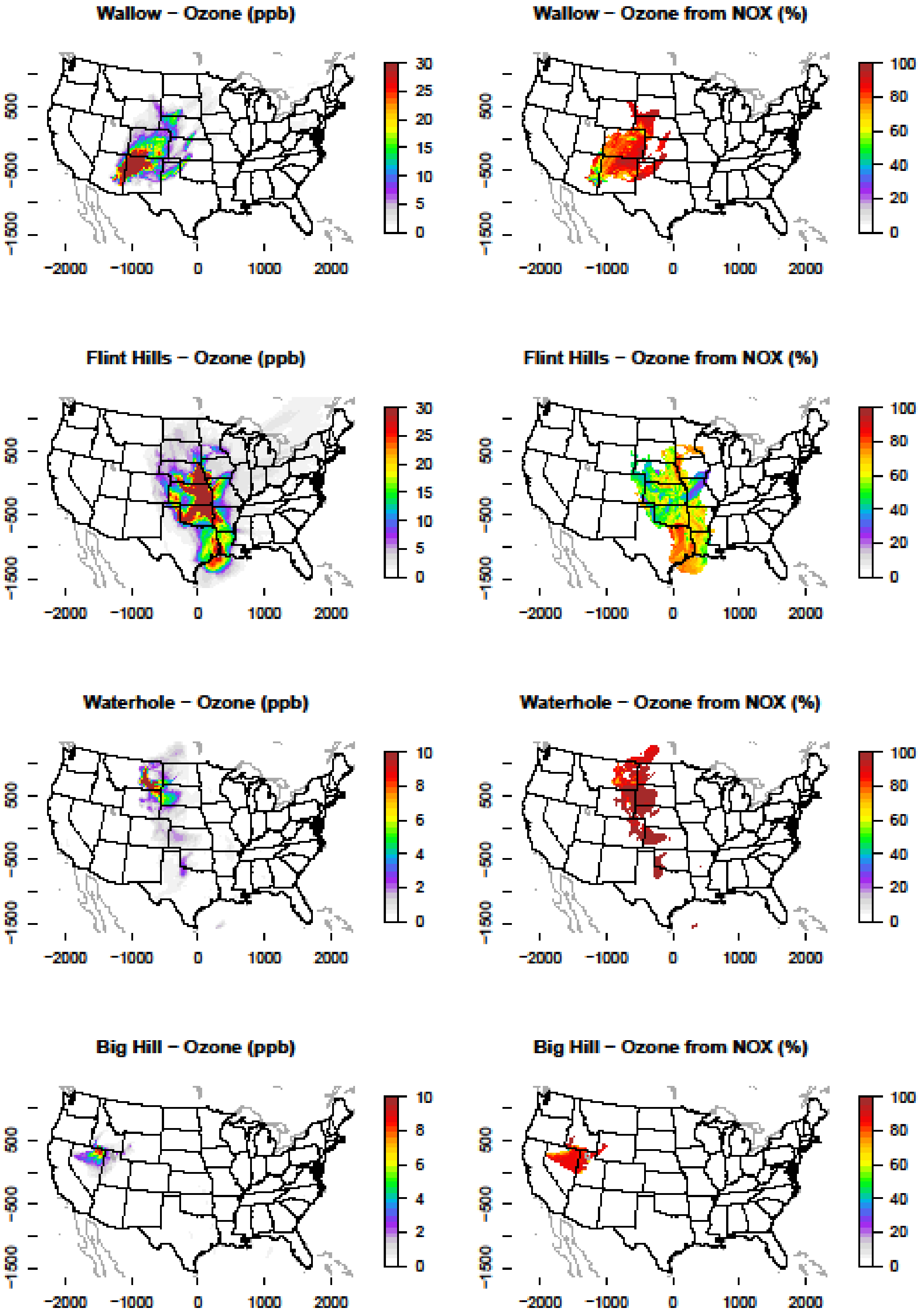
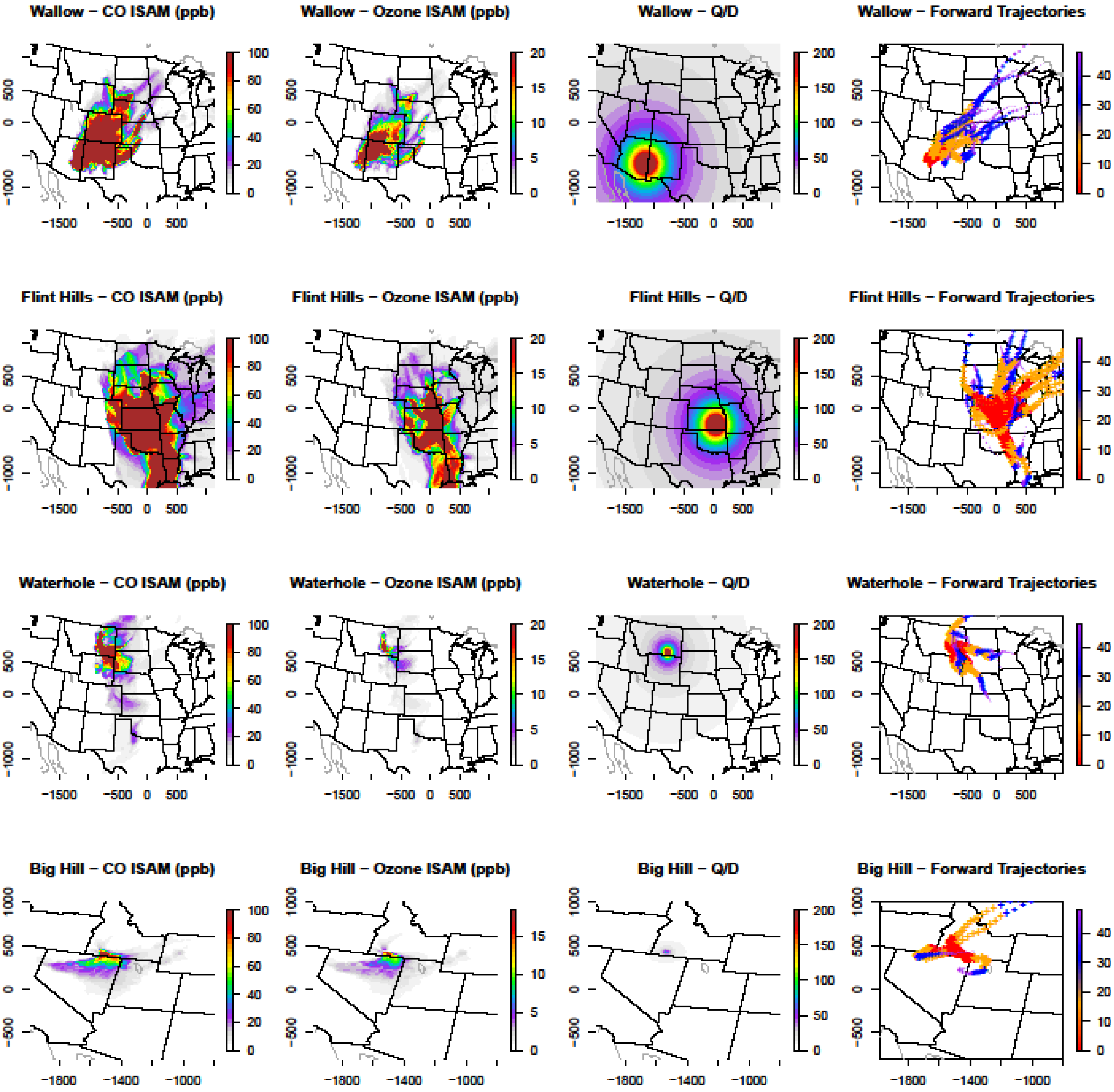


Figure A2-3. Event maximum 1-hour CO (left panels), O_3 (second to left panels), Q/D (second to right panels), and forward trajectories (right panels) shown for multiple fire events. Q/D is based on daily maximum NOX+rVOC emissions from the fire event during the period modeled. Forward trajectories are 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.


Wallow – CO ISAM (ppb)

Wallow – Ozone ISAM (ppb)

Wallow – Q/D

Wallow – Forward Trajectories

Flint Hills – CO ISAM (ppb)

Flint Hills – Ozone ISAM (ppb)

Flint Hills – Q/D

Flint Hills – Forward Trajectories

Waterhole – CO ISAM (ppb)

Waterhole – Ozone ISAM (ppb)

Waterhole – Q/D

Waterhole – Forward Trajectories

Big Hill – CO ISAM (ppb)

Big Hill – Ozone ISAM (ppb)

Big Hill – Q/D

Big Hill – Forward Trajectories

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

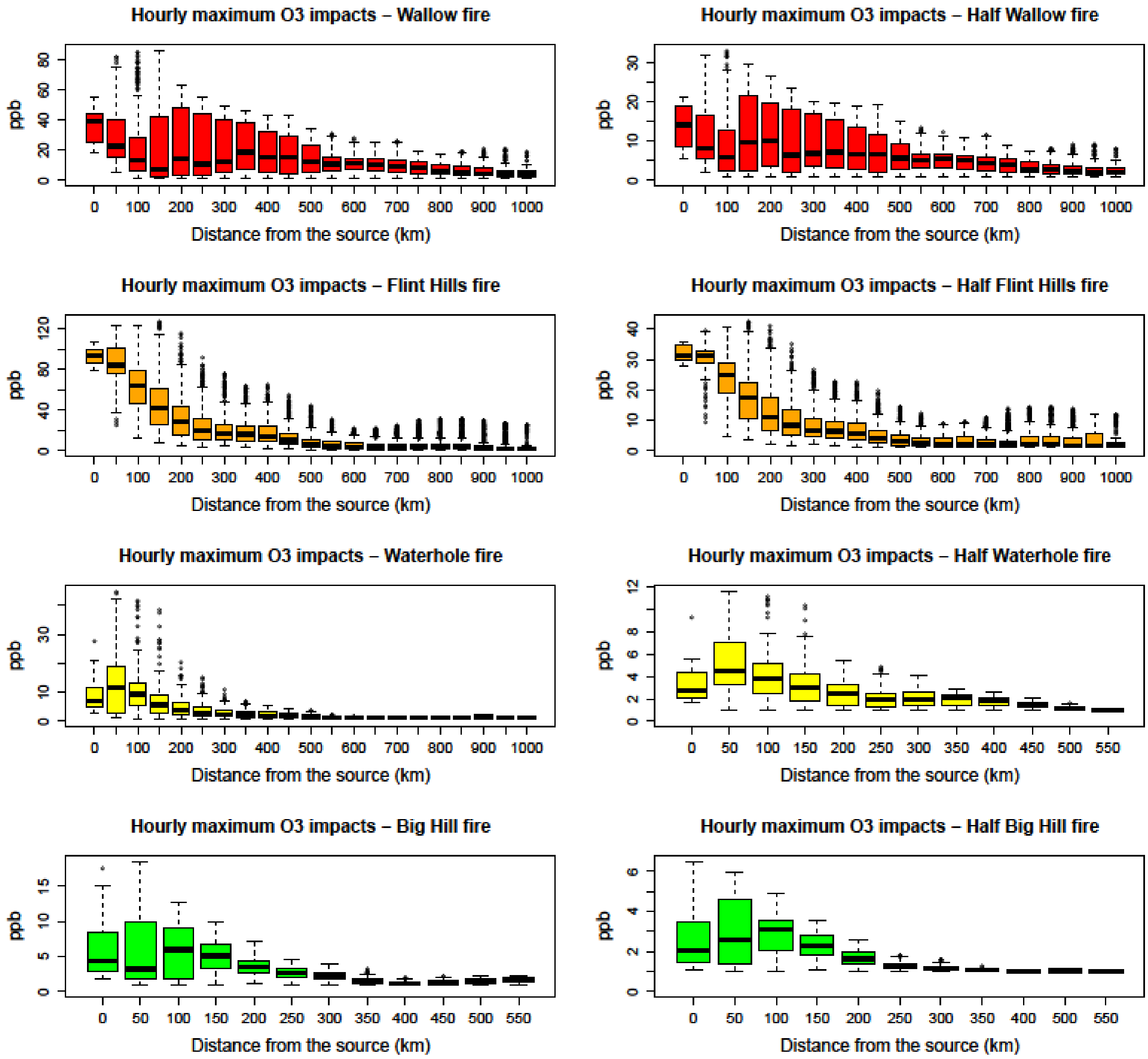


Figure A2-5. Hourly maximum O_3 impacts from the first two days of each fire event (Table A2-1) shown by Q/D. O_3 impacts only up to 1000 km from the fire have been included in this analysis.

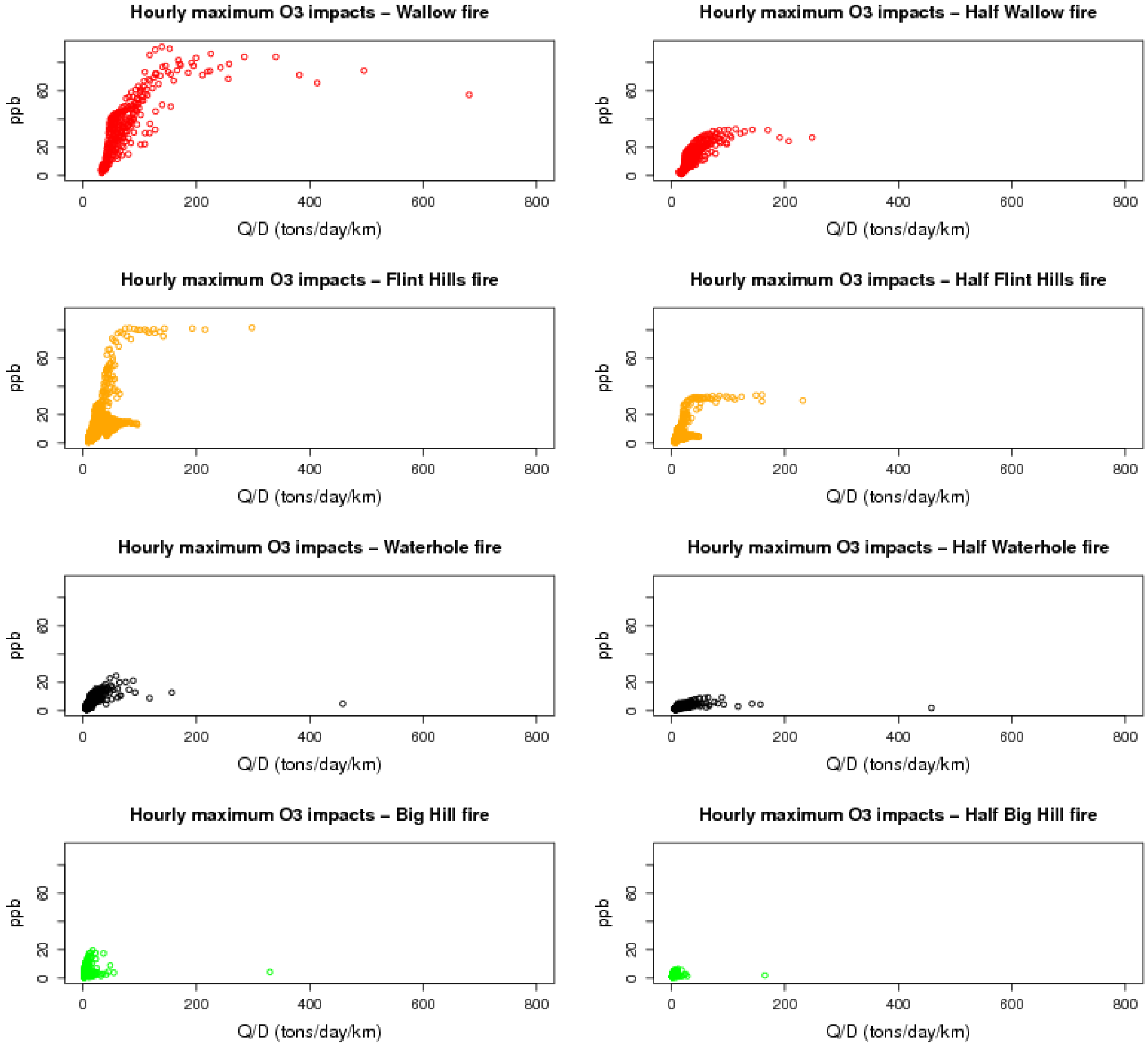
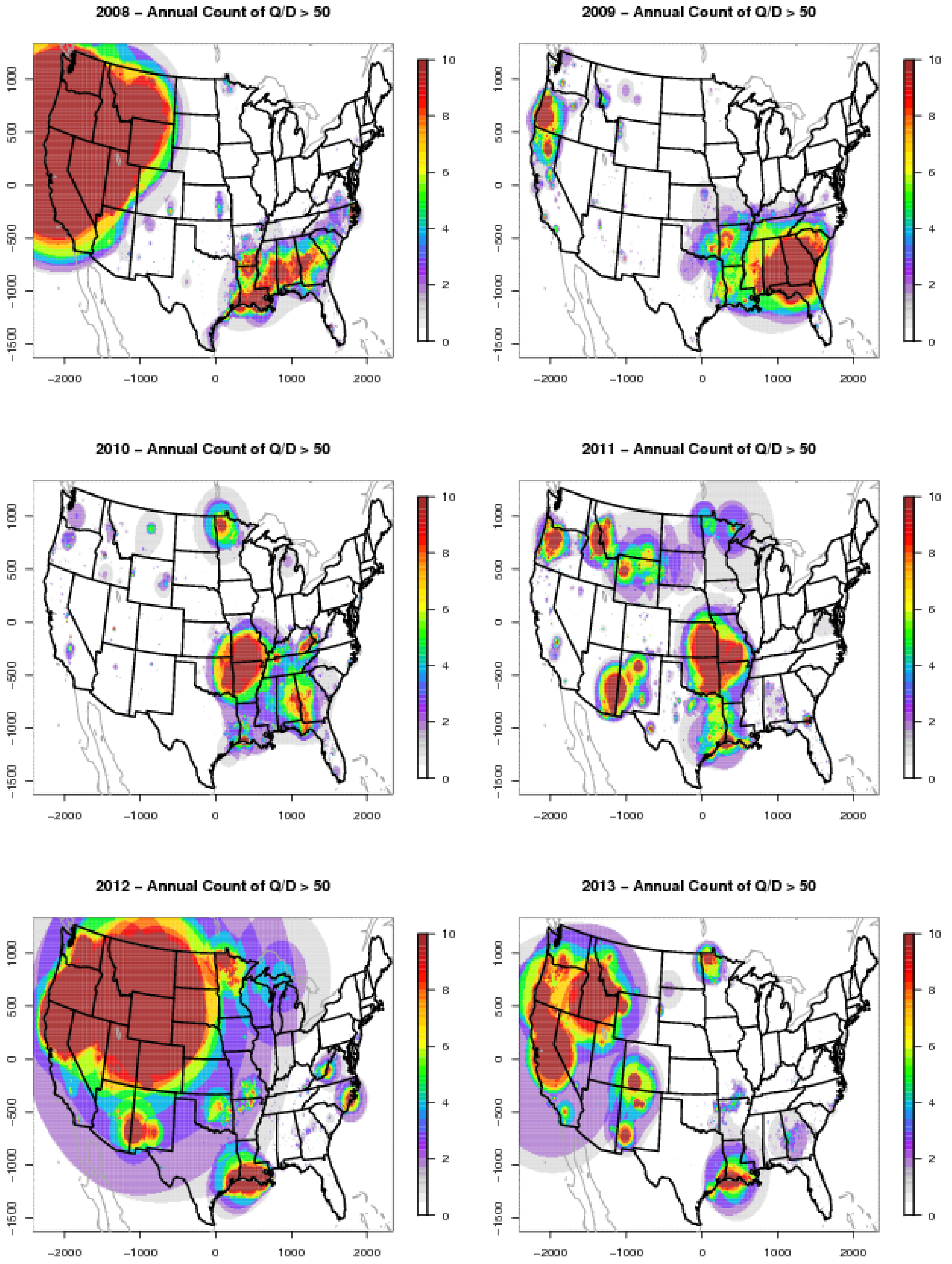


Figure A2-6. Count of days with NO_X+rVOC Q/D > 50 for 2008 through 2013. Note scale has been capped at 10 to more easily distinguish the values below 10. Red may actually indicate 10 or greater than 10.


2008 – Annual Count of Q/D > 50

2009 – Annual Count of Q/D > 50

2010 – Annual Count of Q/D > 50

2011 – Annual Count of Q/D > 50

2012 – Annual Count of Q/D > 50

2013 – Annual Count of Q/D > 50

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.

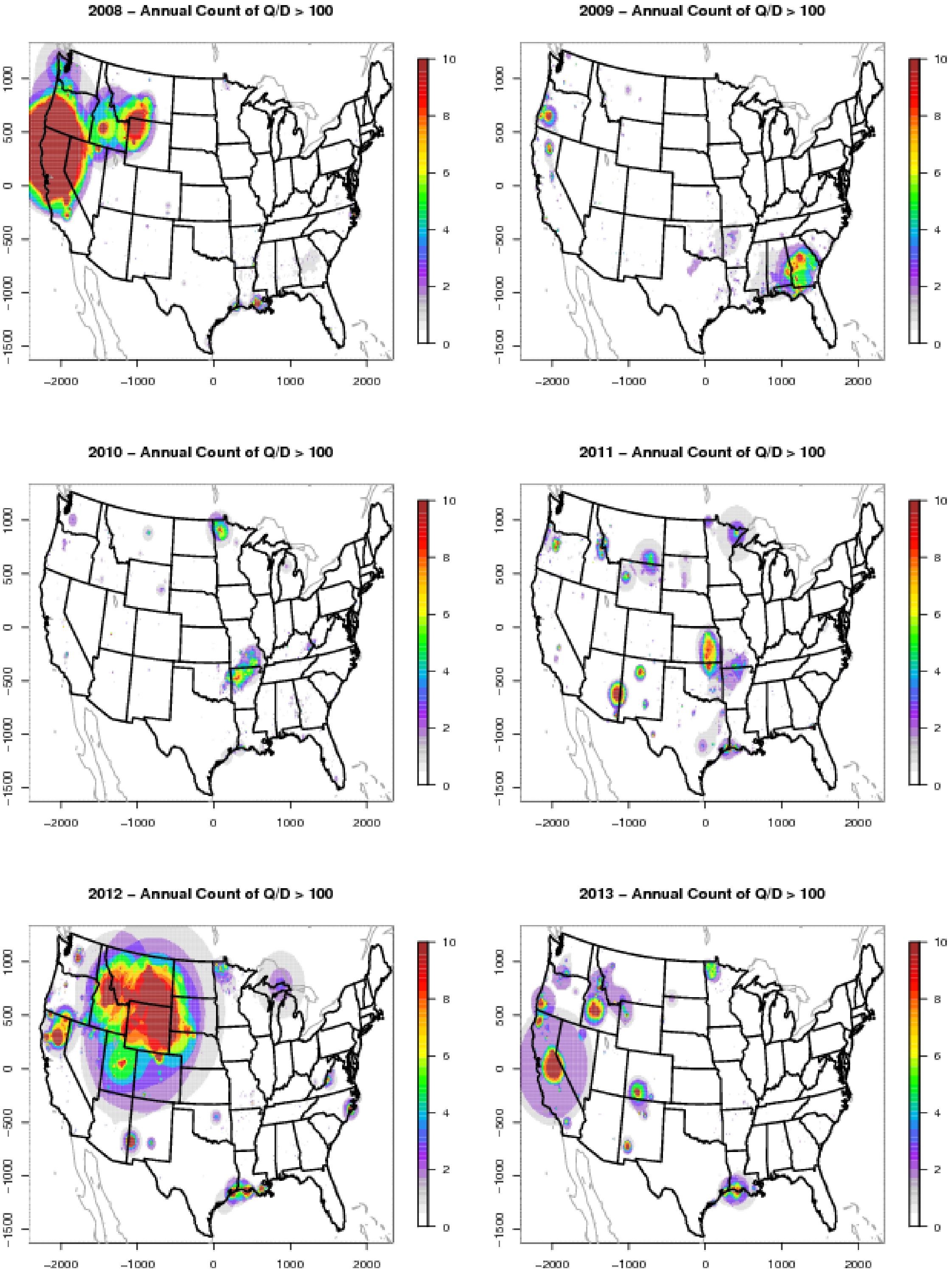
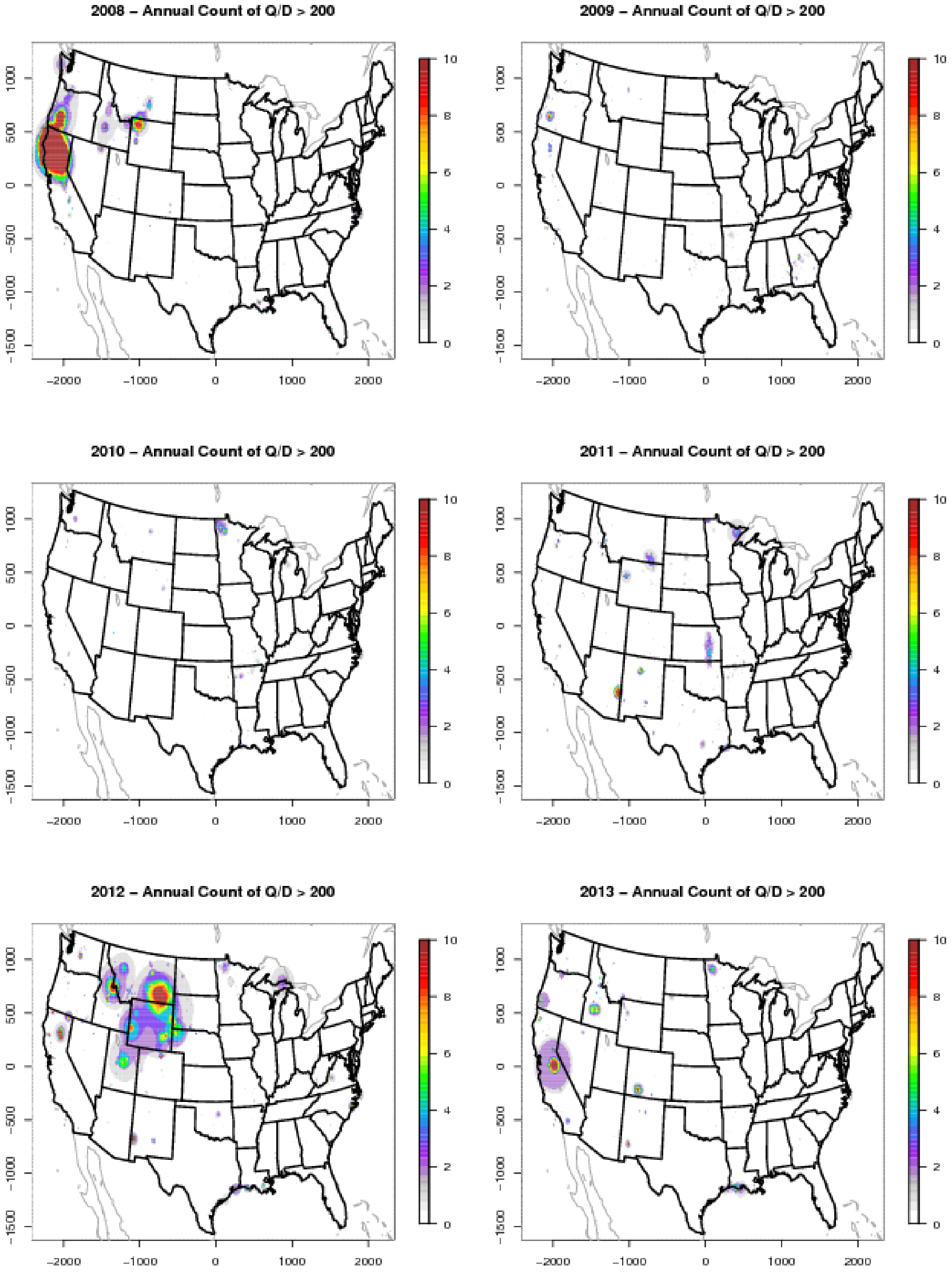


Figure A2-8. Count of days with NO_X+rVOC Q/D > 200 for 2008 through 2013. Note scale has been capped at 10 to more easily distinguish the values below 10. Red may actually indicate 10 or greater than 10.



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. Additionally, ARL has been archiving NAM hybrid sigma pressure coordinate data since March 2010. These data are in three domains: CONUS with 12 km, Alaska with 12 km and Hawaii with 2 km horizontal resolution. Air agencies can also use these meteorological datasets for the applications described in the document.
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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