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GUIDANCE DOCUMENT ON TRANSBOUNDARY FLOWS AND EXCEPTIONAL EVENTS FOR AIR ZONE MANAGEMENT

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BACKGROUND ON AIR QUALITY MANAGEMENT SYSTEM ELEMENTS

Air quality is important for all Canadians and it affects many aspects of our lives and our society including human health, the natural environment, buildings and infrastructure, crop production, and the economy. In Canada, air quality management is a responsibility shared among federal, provincial and territorial governments. Through the Canadian Council of Ministers of the Environment (CCME), federal, provincial and territorial governments are working collaboratively to improve air quality by implementing the Air Quality Management System (AQMS)[1]. Key elements of AQMS include:

1. Air zones – geographical areas that are used to manage local air quality within the provinces and territories in which they are located.
2. Regional airsheds – broad geographic areas that encompass a number of air zones and may cross provincial, territorial and international boundaries. They provide a framework for interjurisdictional collaboration to address transboundary air quality issues.
3. Canadian Ambient Air Quality Standards (CAAQS) – health and environmental-based air quality objectives to further protect human health and the environment and to provide the drivers for air quality improvement across the country.
4. Air zone management framework – a framework to manage air quality in air zones.
5. Base-level industrial emissions requirements (BLIERs) – emission requirements that are intended to apply to major industrial sectors or equipment types to ensure that significant industrial sources achieve a good base-level of performance.
6. Mobile sources – to build on the existing range of federal, provincial and territorial initiatives aimed at reducing emissions from the transportation sector.

In addition to being endorsed by CCME, CAAQS have also been established as ambient air quality objectives by the federal government under the *Canadian Environmental Protection Act, 1999*.

In some cases, the ambient concentrations of air pollutants measured in air zones are influenced by air pollutants from transboundary flows and exceptional events which jurisdictions have little or no direct control over. This document provides guidance to provinces and territories wanting to consider influences from transboundary flows and exceptional events on the measured concentrations of air pollutants within air zones.

[1] Although Québec supports the general objectives of AQMS, it will not implement the System since it includes federal industrial emission requirements that duplicate Québec's Regulation. However, Québec is collaborating with jurisdictions on developing other elements of the system, notably air zones and airsheds.

1.0 INTRODUCTION

AQMS requires provinces and territories[2] to regularly publish air zone reports which include information on the achievement status and management levels of the CAAQS based on the measured concentrations of air pollutants. In addition to contributions from local anthropogenic sources, some of these concentrations may also contain contributions, or *influences*, from transboundary flows (TF) and exceptional events (EE) (including natural sources) over which a jurisdiction has little to no control.

Air zone reports must provide the achievement status of CAAQS based on all measured concentrations irrespective of the influences that contributed to them. However, under AQMS, provinces and territories have the option of claiming in air zone reports that a given CAAQS exceedance could have been influenced by TF or EE as supported by evidence. They can also claim, as supported by evidence, that an air zone could be at a lower management level after consideration of TF-EE influences.

This document supersedes section 7 (Accounting for Transboundary Flows and Exceptional Events) of the CCME 2012 Guidance Document on Achievement Determination, Canadian Ambient Air Quality Standards for Fine Particulate Matter and Ozone. It is primarily intended for use by provinces and territories and provides guidance on the procedures to use for considering the influences of TF-EE on CAAQS exceedances and management levels. The use of common definitions for TF-EE and the weight of evidence (WOE) approach, as outlined in this document, helps ensure consistent procedures across the country for the consideration of TF-EE influences. Stakeholders and interested parties may want to read this document to gain an understanding of how provinces and territories account for the influences of TF-EE.

More information on AQMS and guidance on its implementation is available on ccme.ca.

2.0 INFLUENCE TYPES

This section defines the three major source categories that can influence the measured concentrations of air pollutants.

2.1 Local Sources

Local sources are reasonably controllable or preventable emissions of air pollutants from anthropogenic (i.e., human influence-related) sources located in a given province or territory. Examples of local sources include industry, motor vehicles, power generation utilities, marine vessels, wood-burning appliances and burning of land clearing debris.

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[2] Although Québec supports the general objectives of AQMS, the province will not implement the System since the System calls for federal industrial emission requirements that duplicate Québec regulations. However, Québec is collaborating with jurisdictions on developing other elements of the system, notably air zones and airsheds.

2.2 Transboundary Flows

Transboundary flows (TF) refer to emissions of anthropogenic air pollutants that are released in one jurisdiction and transported or moved by winds and weather systems into another. TF includes:

1. anthropogenic air pollutants released in one Canadian province or territory and transported into another
2. anthropogenic air pollutants transported into Canada from another country.

As air pollutants move through the air, they may transform into different substances. For example, sulphur dioxide gas can undergo chemical reactions in the air and transform into particulate sulphate and contribute to the $PM_{2.5}$ concentrations in another jurisdiction. TFs include pollutants that are both directly emitted to the air (referred to as primary pollutants) and those that form in the air (secondary pollutants).

For clarity, the influence of anthropogenic emissions from one air zone into another located in the same province or territory is a local source influence, and not TF.

2.3 Exceptional Events

Exceptional events (EE) include the following types of sources:

1. forest fires and other natural sources within or outside Canada
2. prescribed forest fires intentionally ignited for safety or management purposes and which are conducted according to best smoke management practices as outlined, for example, in the CCME *Guidance Document for Canadian Jurisdictions on Open-air Burning* (2016) (excludes intentionally ignited fires of land clearing debris)
3. fires due to arson or other non-controllable or accidental causes, the release of air pollutants for safety reasons, and industrial and non-industrial accidents
4. anthropogenic sources arising from natural phenomena within or outside Canada (e.g., lightning-induced fire at an industrial facility)
5. a sporadic anthropogenic source which satisfies both of the following criteria:
   (a) the source was not reasonably controllable or preventable
   (b) the source was infrequent, meaning that going back three years from the date in which the source is claimed to have influenced the concentrations, the source released air pollutants on no more than two occasions (including the EE being claimed).

Table 2-1 provides examples of EEs that are natural sources or arising from natural phenomena and text box 1 provides an example of how criteria 5(a) and 5(b) would be applied to evaluate if a sporadic source qualifies as an EE. Examples of sporadic sources could include occasional venting events, industrial facility start-ups and shut-downs, burnings of land clearing debris from the same clearing area, etc.

Table 2-1: Example of natural-related exceptional events.

1. Fires caused by lightning (e.g., forest and structure fires)
2. Wind-blown particulate matter (PM) where the PM is of natural origin and undisturbed by human activities
3. The downward transport of ozone from the stratosphere or free troposphere.
4. The production of ozone from lightning
5. Unusual (non-routine) biogenic emissions (e.g. exceptionally high air temperature which could lead to enhanced VOC emissions from vegetation)
6. Emissions from anthropogenic sources as a result of volcanic activities, seismic events and other natural disasters (e.g., industrial explosion arising from a seismic event).

Text box 1: Example for evaluating if a sporadic source qualifies as an EE.

A jurisdiction finds that the elevated $PM_{2.5}$ concentrations measured in an air zone on June 15, 2013 were influenced by the venting of emissions from a local source on the same day. The jurisdiction decides to investigate if this venting qualifies as an EE. It finds that the venting was not for safety reasons, and this means that for the venting to qualify as an EE it must satisfy both criteria 5(a) and 5(b). Based on the provided and available information, the jurisdiction concludes that the venting was not reasonably controllable or preventable and therefore satisfies criterion 5(a).

The jurisdiction evaluates next if the event satisfied criterion 5(b) – the source was infrequent. To evaluate this, the jurisdiction has to determine the total number of venting events from the same source in the prior three-year period up to and including the date in which the source is claimed to having influenced (June 15, 2013). Two cases are discussed as examples.

Case 1. The jurisdiction finds that from June 16, 2010 to June 15, 2013 the source experienced a total of three non-safety venting events (including the one of June 15, 2013). Since criterion 5(b) is not satisfied, the venting event on June 15, 2013 cannot be considered as an EE. Therefore, the jurisdiction cannot claim that the $PM_{2.5}$ concentrations measured on June 15, 2013 were influenced by an EE.

Case 2. The jurisdiction finds that from June 16, 2010 to June 15, 2013 the source experienced two non-safety venting events (including the one of June 15, 2013). Since criteria 5(a) and 5(b) are both satisfied, the venting event on June 15, 2013 can be considered as an EE. Therefore, the jurisdiction can claim that the $PM_{2.5}$ concentrations measured on June 15, 2013 were influenced by an EE.

For clarity, a sporadic source that occurs over several consecutive days is to be considered as a single event. Also, an identified sporadic source in one province or territory and influencing concentrations in another could be considered an EE instead of a TF if it satisfies criteria 5(a) and 5(b).

The influence of meteorological conditions on ambient concentrations due to emissions from local sources is not considered an EE. For example, the accumulation of air pollutants released from local sources is not an EE, even if such conditions are rare. Where the influence of meteorological conditions contributes in occasionally producing elevated concentrations of air pollutants released from local sources, jurisdictions may choose to issue air quality advisories and may request immediate actions by local community members to reduce the contribution of air pollutants. Some jurisdictions have the authority to issue mandatory emission curtailment orders during air pollution episodes[3].

3.0 CONSIDERATION OF TRANSBOUNDARY FLOWS AND EXCEPTIONAL EVENTS INFLUENCES

Provinces and territories can claim TF-EE influences under certain conditions. This section describes the conditions under which these claims can be made.

The concentrations to use for direct comparison to a given CAAQS to determine if it was exceeded and to determine the management level are called CAAQS metric values. The procedures for calculating metric values from the measured concentrations of the corresponding air pollutant are provided in the CCME guidance documents on achievement determination (GDAD) for each CAAQS. In this section, the term *actual metric value* is used to refer to metric values calculated using *all* measured concentrations irrespective of the influence, and *adjusted metric value* is used to refer to metric values calculated after the exclusion of concentrations influenced by TF-EE.

The adjusted metric values are compared to the standards and management levels to determine if an exceedance could have been influenced by TF-EE and to determine if an air zone could be at a lower management level after consideration of TF-EE influences. Table 3-1 provides the three main steps for obtaining adjusted metric values at a monitoring station.

[3] For example, the Ontario Ministry of the Environment, Conservation and Parks can issue orders for the curtailment of the operation of sources of air pollution during air pollution episodes under Ontario Regulation 419/05.

Table 3-1: Steps for obtaining TF-EE adjusted metric values at a monitoring station.

	Action
Step 1	Select the measured concentrations to investigate for TF-EE influences.
Step 2	Apply the WOE approach to gather evidence to support the claim that the identified concentrations in Step 1 could have been influenced by TF-EE.
Step 3	Exclude the concentrations found to be influenced by TF-EE and calculate the adjusted CAAQS metric value.

The adjusted metric value in Step 3 is calculated following the same procedures provided in the GDAD of each CAAQS, with the only exception that the data completeness requirement is not to be applied. The Annex provides an example of the three steps approach.

For a given monitoring station and CAAQS, the three-step process can be repeated until the desired outcome is obtained (i.e., the adjusted metric value does not exceed the standard, or the adjusted metric value falls in the lowest management level). Some provinces and territories may opt to evaluate all concentrations for TF-EE influences while others may opt only for a minimum number of concentrations as dictated by the statistical form and value of the standard and the desired outcome. Also, some provinces and territories may opt to calculate an adjusted metric value after every (or several) excluded concentrations to verify if the desired outcome is reached, while others may opt to calculate an adjusted metric value only after the exclusion of all concentrations influenced by TF-EE[4]. The Annex provides an example of the 3-step approach where the desired outcome is to evaluate if a CAAQS exceedance was influenced by TF-EE by evaluating only a minimum number of concentrations.

To claim that a CAAQS exceedance at a monitoring station was influenced by TF-EE, the adjusted metric value for the station must be less than or equal to the corresponding standard. For air zones, the GDAD mention that an air zone achieves a CAAQS if the metric values at *all* CAAQS-reporting stations in the air zone do not exceed the standard. Accordingly, to claim that a CAAQS exceedance in an air zone could have been influenced by TF-EE, this must be the case for *all* the metric values that exceed the standard.

The procedures for assigning the air zone management levels are specified in the *Guidance Document on Air Zone Management* (CCME, 2019). For the air zone management level, the GDAD mentions that the management level is to be assigned based on the highest CAAQS metric value. Therefore, the lowest management level that can be assigned to an

[4] For example, for the ozone CAAQS the process would ultimately stop when four highest concentrations not influenced by TF-EE are obtained. For exceedances of the annual SO_2 CAAQS, the process would ultimately stop when all concentrations exceeding the annual standard are evaluated.

air zone will be based on the highest metric value among the adjusted metric values for stations influenced by TF-EE and the actual metric values for stations not influenced by TF-EE. This means that to be able to claim that an air zone could be at a lower management level after consideration of TF-EE influences, the actual metric value at stations not influenced by TF-EE and the adjusted metric values at stations influenced by TF-EE must all fall within the same management level. Table 3-2 provides an example of this.

Table 3-2: Example for claiming lower management level after consideration of TF-EE.

Air Zone	CAAQS reporting station	Management level based on actual metric value	Management level based on adjusted metric value	Management level assigned to air zone	Can claim be made that air zone is at lower management level after TF-EE
A	1	Yellow	Green	**Green**	**Yes**
B	1	Orange	Yellow	**Yellow**	**Yes**
	2	Yellow	Not applicable		
C	1	Red	Orange	**Red**	**No**
	2	Red	Green		
	3	Red	Not applicable		

Procedure-wise, to evaluate if an air zone could be at a lower management level after consideration of TF-EE, the 3-step approach outlined in Table 3-1 would be applied first to the station with the highest metric value. The resulting adjusted metric value may then fall in a management level that is lower than the management level based on actual metric values at other stations. As such, the 3-step approach would next be applied to the station with next higher management level and so on as warranted. The process stops when any of the following occur:

1. an adjusted metric value cannot go further down to a lower management level
2. all adjusted metric values go down to the same management level as the highest actual metric value at stations not influenced by TF-EE
3. the adjusted metric values and actual metric values at stations not influenced by TF-EE are *all* in the Green management level.

Section 4 provides examples of approaches and methods that could be used to identify concentrations for potential investigations for TF-EE influences. Section 5 discusses the WOE approach for Step 2.

4.0 CONCENTRATIONS TO INVESTIGATE FOR TRANSBOUNDARY FLOWS AND EXCEPTIONAL EVENTS INFLUENCES

Step 1 of the three steps approach for the consideration of TF-EE influences requires the selection of concentrations to investigate for TF-EE influences through the WOE. Since the WOE approach is resource-intensive, the concentrations to select for investigation could be selected strategically.

A knowledgeable air quality data analyst could begin by selecting the higher concentrations which seem to be “outliers” and which affect the achievement status of the CAAQS or management level. To build this knowledge base, existing historical data can be used to construct charts detailing how concentrations of air pollutants typically vary temporally (e.g., diurnally, day of week, monthly and seasonally) at each monitoring station. This is done by simply averaging the concentrations over the specified time period. Charts could also be constructed detailing how related air pollutants vary with respect to each other temporally. For example, primary pollutants emitted from a same source are likely to display related temporal patterns. If some measured concentrations deviate from these typical patterns, it may signal the influence of unusual circumstances and these outlier concentrations could then be selected for investigation for TF-EE influences.

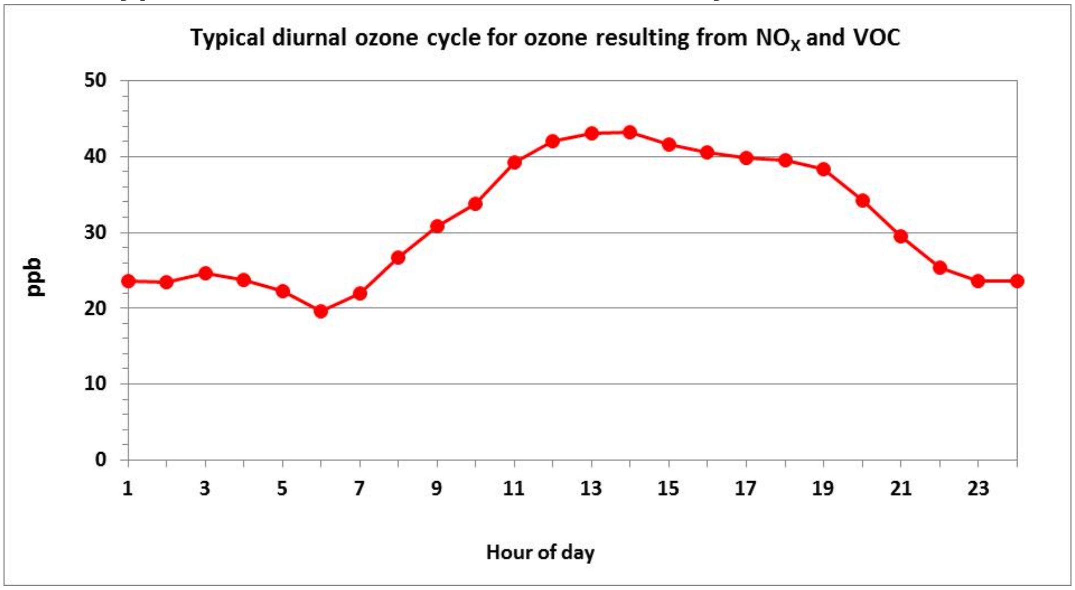
The rest of this section provides examples of information and analyses that could be used to identify outlier concentrations for potential investigation for TF-EE influences. Some of these analyses can also be used as part of the WOE discussed in section 5.

4.1 Ozone Outlier Concentrations

Except for ozone formed from lightning, ozone formation requires sunlight. As such, ozone only forms during daylight hours and ozone concentrations in the boundary layer[5] typically follow the diurnal cycle displayed in Figure 4-1. The concentrations begin to increase in the morning to reach maximum values in the afternoon to early evening and then gradually decrease to reach minimum values during the night. The nighttime minimum occurs because ozone is no longer formed and it is depleted as it reacts with other substances in the air or deposits on surfaces.

[5] The “boundary layer” is the layer of the atmosphere closest to the earth surface. The boundary layer is in direct contact with the earth surface and, as such, it is the most affected by surface features such as temperature and surface roughness. The boundary layer height (or its thickness) is typically the highest in summer months (at times reaching 3000 m) and lowest in winter months.

Figure 4-1: Typical diurnal ozone concentration cycle.



Ozone concentrations that are not consistent with the typical diurnal pattern, such concentrations increasing during the night, could be investigated for TF-EE influences. Some EE influences include ozone formed in the *free* troposphere[6] and ozone formed in the stratosphere. Some meteorological conditions enable tropospheric and stratospheric ozone to be transported downward in the boundary layer and contribute to the ozone measured at monitoring stations. These influences can occur in all hours of the day and can be more pronounced at stations at higher elevations above ground than stations near sea-level. Section 5.1 provides more information on stratospheric influences.

Other EE influences include lightning and forest fires. Lightning strikes can lead to the formation of ozone and forest fires release ozone precursors that can lead to ozone formation. Both local and distant forest fires can be evaluated since the ozone formed in the boundary layer can travel long distances.

While both local and transboundary sources of the main ozone precursors (nitrogen oxides and volatile organic compounds) can contribute in producing the ozone diurnal cycle displayed in Figure 4-1, TF influences can also be investigated for outlier concentrations.

4.2 Temporal Variation of Air Pollutants

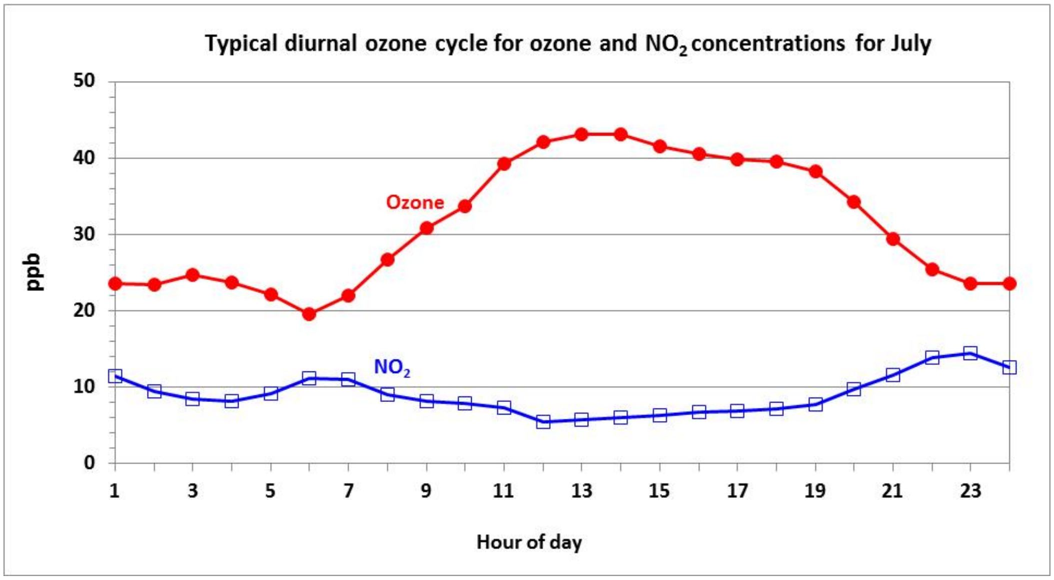
Long-term (or historical) data can be used for any air pollutants to construct charts which document how, on average, concentrations vary with time. An example was provided for ozone in Figure 4-1. If measured concentrations deviate from these typical patterns, it may

[6] The “free” troposphere is that part of the troposphere that is above the boundary layer. It is “free” in the sense that it is not affected as much by surface features.

signal the influence of unusual circumstances and the outlier concentrations could then be selected for investigation for TF-EE influences.

In addition to these single pollutant charts, charts can also be constructed which show how *related* air pollutants typically vary with respect to each other with time. For example, for ozone resulting from nitrogen dioxide (NO_2), ozone and NO_2 concentrations typically exhibit the inverse diurnal cycle illustrated in Figure 4-2. This figure shows the well-documented inverse relationship between ozone and NO_2 concentrations, with ozone concentrations typically increasing as NO_2 concentrations decrease. For pollutants released from the same source, their concentrations at a nearby monitoring station are likely to exhibit similar temporal trends.

Figure 4-2: Typical diurnal ozone and NO_2 concentration cycle.



The construction of these charts can be used to assist in identifying outlier concentrations to investigate for TF-EE influences. For the example in Figure 4-2, if NO_2 concentrations continue to increase as ozone increases, it may suggest that something unusual occurred.

4.3 Spatial Relationships of Concentrations

For air zones containing several monitoring stations for a given air pollutant, analyses can be conducted using long-term data to evaluate the spatial relationship in measured concentrations between two or more stations. A departure from the typical relationship may be used to identify the concentrations to investigate for possible TF-EE influences.

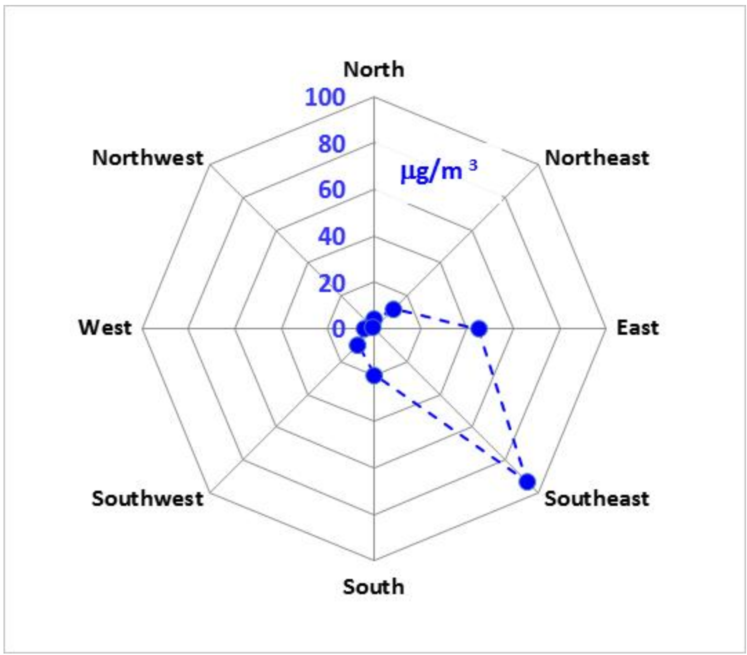
For example, analyses of long-term $PM_{2.5}$ data in an air zone indicated that concentrations above the $PM_{2.5}$ standard occur simultaneously at several stations that are relatively close to each other and this is due to local sources. If elevated $PM_{2.5}$ concentrations are measured only at one station, it may suggest something unusual occurred and the outlier concentrations could then be investigated for TF-EE influences.

4.4 Air Pollutant Wind-rose

An air pollutant wind-rose is a chart that shows how average concentrations of an air pollutant measured at a monitoring station vary according to wind direction and speed. The simplest air pollutant wind-rose is developed by first grouping the measured concentrations of the given air pollutant according to the wind direction quadrant from which the wind is coming from and then calculating the average concentration under each quadrant. Since wind direction can be very variable under light wind speeds (~≤ 1 m/s), concentrations under light wind speeds are typically grouped together.

Air pollutant wind-roses are usually developed using long-term data. Figure 4-3 provides an example of a $PM_{2.5}$ wind-rose. In this example, the $PM_{2.5}$ concentrations measured at the monitoring station are highest (on average) with winds coming (or blowing) from the southeast quadrant and the lowest with winds from the southwest to the northeast quadrants. For this example, this distribution reflects emissions from a local $PM_{2.5}$ source located southeast of the station.

Figure 4-3: Example of a $PM_{2.5}$ pollutant wind-rose.



Air pollutant wind roses can be used to assist in identifying concentrations to investigate for possible TF-EE influences. For the example in Figure 4-3, if elevated $PM_{2.5}$ concentrations are measured with winds coming from the northwest, it may be an indication that something unusual occurred and the outlier concentrations could then be investigated for TF-EE influences.

5.0 WEIGHT OF EVIDENCE TO SUPPORT TRANSBOUNDARY FLOWS AND EXCEPTIONAL EVENTS INFLUENCES

Under Step 2 of the three steps approach for the consideration of TF-EE influences, provinces and territories have to gather evidence that supports the claim that concentrations could have been influenced by TF-EE. Since it is challenging and resource-intensive to quantitatively estimate the influence of given sources on measured concentrations, the decision regarding whether concentrations could have been influenced by TF-EE can be reached based on a “weight of evidence” approach.

Under the WOE approach, jurisdictions would conduct several analyses whose results, taken collectively, converge to provide strong support for the claim that concentrations could have been influenced by TF-EE. There may be cases where an exact TF-EE influence may be challenging to identify, and for these cases the evidence could be gathered to support the claim that local sources could not have been a major influence.

Measured concentrations that are suspected of being influenced by the same TF-EE influence can be evaluated collectively for the TF-EE influence instead of individually. For example, forest fires can typically influence many concentrations in a day (or days) and influence more than one monitoring station simultaneously. Such events can be evaluated collectively.

The rest of this section provides examples of analyses that could be conducted to support the occurrence of TF-EE influences. “Analyses” is used here in a broad sense and includes any pertinent information and data in relation to the TF-EE influence under investigation. The provided examples are not exhaustive and any other sound analyses can also be used, including those discussed in section 4. The number and type of analyses to conduct can vary on a case-by-case basis depending on the complexity of the circumstances. For example, in simple cases like forest fires satellite imagery may be sufficient, while in more complex cases like ozone transport from the stratosphere several lines of evidence may be required.

Provincial and territorial air quality experts, in consultation with the federal government as needed and as resources allow, would use the results from the analyses in deciding whether the gathered evidence provides sufficient support for the claimed TF-EE influence.

5.1 Stratospheric Ozone

Stratospheric intrusions where air from the stratosphere is brought downward across the tropopause[7] and into the free troposphere can occur only under some specific meteorological conditions. Some of these conditions include: the passage of very active cold weather fronts[8] as discussed in Knowland *et al*. (2017), Trickl *et al*. (2014) and Lin *et*

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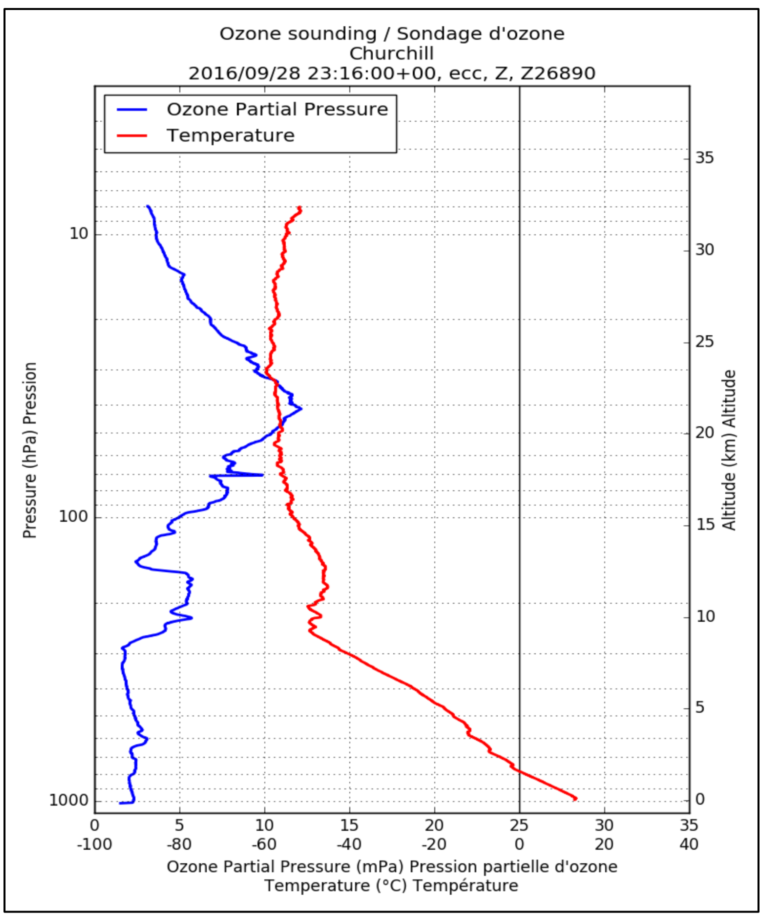
[7] The *tropopause* is a thermally stable layer of air that separates the troposphere and the stratosphere.

[8] Not all cold fronts are associated with stratospheric intrusions.

al. (2012). A characteristic of stratospheric air is its very low water vapor content, or dryness. As such, non-aged stratospheric air that is rapidly transported downward with little mixing with tropospheric air will display very low relative humidity (Trickl *et al*., 2014). Relative humidity could therefore be investigated as part of the WOE for a stratospheric influence. However, the analyses to support a stratospheric influence are quite complex. Examples of such analyses are provided in Wyoming (2012), Ute Indian Tribe *et al*. (2016) and Kaldunski *et al*., (2017).

Vertical ozone measurements could also be investigated as part of the WOE to support ozone influences from the free troposphere and stratosphere. Vertical ozone profiles from the ground up to about 35 km in the stratosphere are available for several locations in Canada through the World Ozone and Ultraviolet Radiation Data Center of the World Meteorological Organization (WMO). Ozone measurements are made with a balloon-borne instrument, which rises in the air and moves with the wind. Figure 5.1 is an example of a vertical ozone profile from Churchill, Manitoba.

Figure 5-1: Example of a vertical ozone profile from Churchill.



5.2 Wind Direction Analyses

Air pollutants released from a source will be transported in a general “downwind” direction from the source. This implies that the locations that are more likely to be influenced by emissions from the source are those located downwind. Conversely, the “upwind” direction from the station provides an indication of the locations where emissions from an unknown source that influenced the station may have originated. Therefore, support for the claim that a *nearby* transboundary source or EE influenced the concentrations at a station could include a wind direction analysis. Text box 2 provides an example of how wind direction analysis can be used to identify an unknown EE.

Text box 2: Example of wind analyses to identify an exceptional event.

The 24-hour average $PM_{2.5}$ concentration for August 15, 2015 was higher than the standard at a station located in a residential area and where there is no known source of $PM_{2.5}$ nearby. The jurisdiction wants to identify the source(s) that could have influenced the concentrations. The jurisdiction begins with a wind analyses and it finds that on August 14 and 15 the predominant surface wind direction as measured at a nearby airport was from west to east. The westerly winds likely imply that any source that influenced the monitor could have been located westward from the station, which is the “upwind” direction.

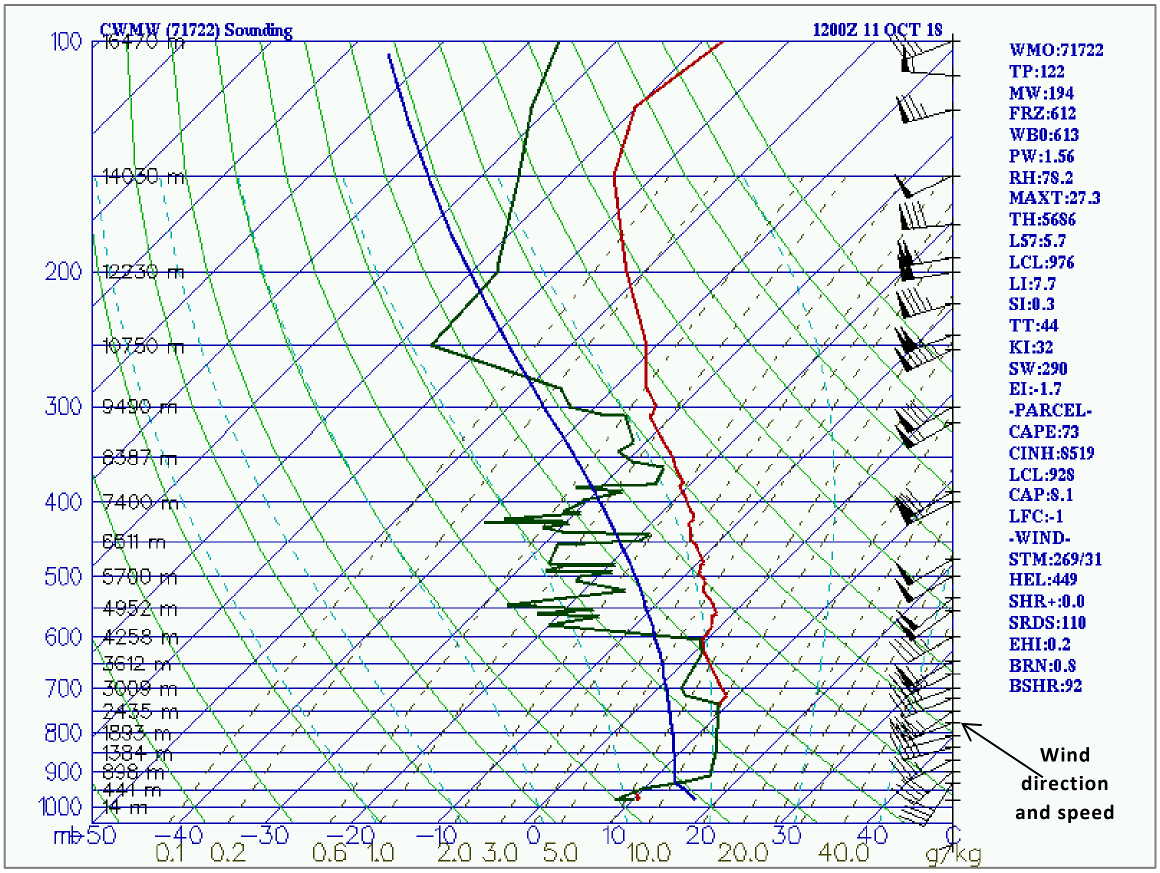
Not finding any obvious source westward of the station that may have influenced the concentrations, the jurisdiction contacts the local fire department where it is informed that an apartment building had been on fire during parts of August 14 and 15. Locating the apartment on a map, the jurisdiction finds that on August 14 and 15 the monitoring station was downwind of the fire. It therefore concludes that the elevated concentrations on August 15 were due to the fire at the apartment building, which qualifies as an EE.

There are a number of caveats to be aware of with wind direction analyses. These analyses are mostly applicable for relatively short distances between a source and a monitor since the released pollutants do not follow a straight path because the wind speed and direction vary with time and space (horizontally and vertically). For large distances, air parcel trajectories are more appropriate and they are discussed in section 5.3.

Also, the wind direction as measured by a monitor near the ground is not necessarily the same as the wind direction at stack height and it is not unusual, especially during nighttime, that wind direction near the ground and at stack height are opposite from each other. In mountainous terrains and valleys these issues are amplified because of complex flow patterns. These caveats imply that caution should be applied when using wind analyses in identifying potential sources that may have influenced the measured concentrations.

Some air quality monitoring stations also measure wind speed and direction. If wind is not measured at an air quality monitoring station, historical wind data can be obtained for many locations in Canada through the web site of Environment and Climate Change Canada (ECCC). The winds measured above ground can be obtained from rawinsondes (or upper air soundings) as provided, for example, by the College of DuPage's Next Generation Weather Lab. Figure 5-2 is an example of an upper air sounding. In addition to wind speed and direction, upper air soundings provide a host of other meteorological information that can also be used as part of the WOE for stratospheric ozone intrusions.

Figure 5-2: Upper air sounding from Maniwaki at 7 a.m. EDT, October 11, 2018.



5.3 Air Parcel Trajectories

The air (or atmosphere) can be viewed as consisting of tiny "air parcels" with porous boundaries that allow atmospheric substances to continuously move in and out of them. These air parcels can move horizontally and vertically according to the prevailing meteorological conditions and as they pass over an emission source, air pollutants are released into them.

An air parcel trajectory can be viewed as being the "path" followed by a given air parcel as it is transported through the atmosphere. This path depends on the prevailing winds that vary in space and time and is estimated from wind models. Trajectories can be modelled going forward or backward in time from a given starting location and time. The red solid line in Figure 5-3 is an example of a modelled back-trajectory of an air parcel. Based on this trajectory, 72-hours prior to its arrival at Toronto on August 18, 1998 at 14:00 EDT, the air parcel was in the middle of Hudson Bay.

Figure 5-3: Example of a back-trajectory.

A 72-hour back-trajectory of an air parcel that was over Toronto on August 18, 1998 at 14:00 EDT.

Air parcel trajectories can be used to identify potential sources at the regional scale (i.e., hundreds to thousands of kilometres). If it is suspected that a transboundary source region influenced the concentrations measured at a monitor, a back-trajectory starting at the location of the station at or near the time that the concentrations were measured can be modelled. If the back-trajectory passes over the transboundary emission source region, it provides support for the TF influence. If it is suspected that a local source did not influence an elevated concentration measured at a station, forward trajectories starting at the location of the local source can be modelled. If the trajectory does not pass near the monitoring station, it provides support for the claim that the local source could not have been a major influence.

There are different trajectory models: there are models where the trajectory is constrained at a fixed height above ground and models where the trajectory also changes with height. The model to use, the starting location, height and time, and the duration of the trajectory are all at the discretion of the jurisdiction depending on the situation under consideration[9]. A widely used model for calculating trajectories is the HYSPLIT model and the Air Resources Laboratory of the U.S. National Oceanic and Atmospheric Administration provides public access to this model.

ECCC can provide some assistance with trajectory analyses as resources allow.

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[9] The accuracy of the trajectory typically decreases with the time duration of the trajectory. For this reason, the duration of trajectories in the literature seldom exceeds 72 hours.

5.4 Forest Fires

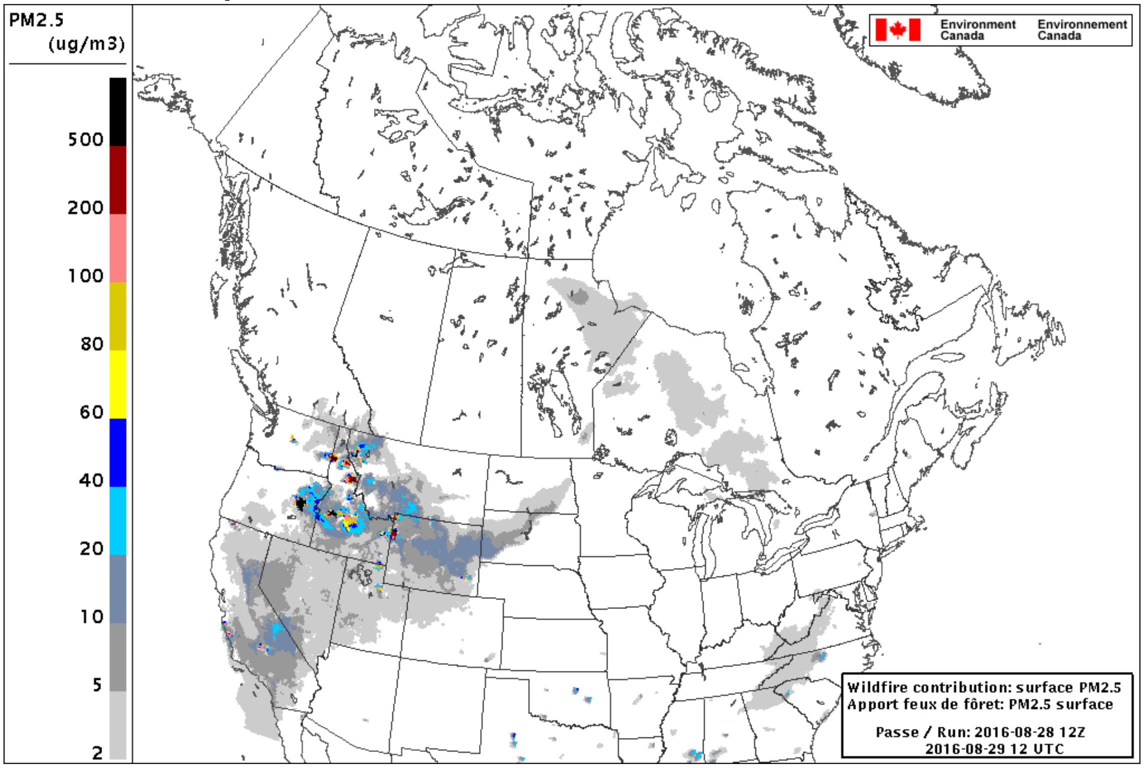
Various analyses can be used to support an influence from forest fires on concentrations. They include the following:

- forward trajectories to show that the smoke plume from the fire was transported towards the affected monitoring station
- satellite imagery to show that the smoke plume from the fire was transported toward the affected monitoring station
- analyses comparing the measured concentrations of air pollutants during the forest fire with those measured before or after the fire. Concentrations of air pollutants, especially $PM_{2.5}$, are typically much higher when influenced by forest fires
- analyses of the spatial extent of the influence of forest fires. Smoke plumes disperse and become wider as the distance from the fire increases. As such, if a community has several $PM_{2.5}$ monitors, it would be expected that many of the $PM_{2.5}$ monitors would be affected by the smoke plume
- registry from FireSmoke Canada and British Columbia's BlueSky showing that the suspected forest fire is on their records
- maps of forecasted $PM_{2.5}$ concentrations from ECCC's Canada's Wildfire Smoke Prediction System (FireWork System) to show that during the suspected forest fire influence the FireWork System did predict $PM_{2.5}$ from forest fires.

ECCC's FireWork System provides daily forecasts of smoke from wildfires in Canada and the United States. An example forecast is shown in Figure 5-4. Although historical forecast information is not available on the ECCC web site, the information could be made available upon request as resources allow through a discussion with the ECCC member of AMC. Archived wildfire smoke forecasts from the FireSmoke Canada system is available from their website for public use.

Smoke plumes can also be detected from regular satellite imagery such as those provided in real-time by ECCC and many other weather agencies and universities. Some historical satellite images are available from the U.S. National Oceanic and Atmospheric Administration web site.

Figure 5-4: Example of an ECCC smoke forecast.



5.5 Air Quality Modelling

Air quality modelling may be especially useful when it is suspected that local sources were not major influences on measured elevated concentrations and an exact TF-EE influence cannot be identified. In these cases, air quality modelling can be used to support the claim that local sources alone could not likely have been the main influence on the measured elevated concentrations.

There are different types of prognostics air quality models that can be used. They range from simple, but well documented dispersion models for point sources, to the highly resource-intensive regional chemical transport models that simulate the dispersion, transport, chemical reactions and deposition of the released pollutants. Through the Support Center for Regulatory Atmospheric Modeling, the United States Environmental Protection Agency provides a number of models that can be downloaded and work on desktop computers. A number of provinces and territories make use of these models. In addition to prognostics models, there are also statistical models that could also be used as part of the WOE approach as deemed appropriate.

Conducting air quality modelling is highly technical and it should only be undertaken by qualified persons. ECCC can provide some assistance as resources allow.

6.0 COMMUNICATION AND REPORTING

Communicating with the Canadian public is an important component of AQMS. Each jurisdiction will regularly publish reports on air quality for each of their air zones and these reports will include the actual metric values and achievement status of the CAAQS for each CAAQS-reporting station and air zone. In cases where the claim is made that a CAAQS exceedance could have been influenced by TF-EE, or that an air zone could be at a lower management level after consideration of TF-EE, the adjusted metric values could also be provided, along with supporting information. When such claims are made, other information that could be provided to an extent practical in an appendix to the report include:

1. identification of the concentrations claimed to be influenced by TF-EE
2. identification of the suspected TF-EE influence
3. a brief conceptual model describing the TF-EE influence (e.g., the meteorological conditions)
4. the WOE analyses to support the claims.

7.0 DISCUSSION

The approach for considering TF-EE influences on CAAQS exceedances and management level described in this document assumes that the excluded concentrations contained no contribution from local sources. This assumption is made because it is challenging to quantitatively estimate the influence from each source. However, it is important to note that this assumption is not always applicable. In some cases, while there may have been a TF-EE influence, the influence from local sources alone could be sufficient to place an air zone in the Red management level, for example, even without the TF-EE influences.

The potential effect of excluding concentrations influenced by TF-EE is to lower the management level for air zones. For example, while the actual metric value places an air zone in the Red management level, the TF-EE adjusted metric values may place the air zone in the Yellow management level.

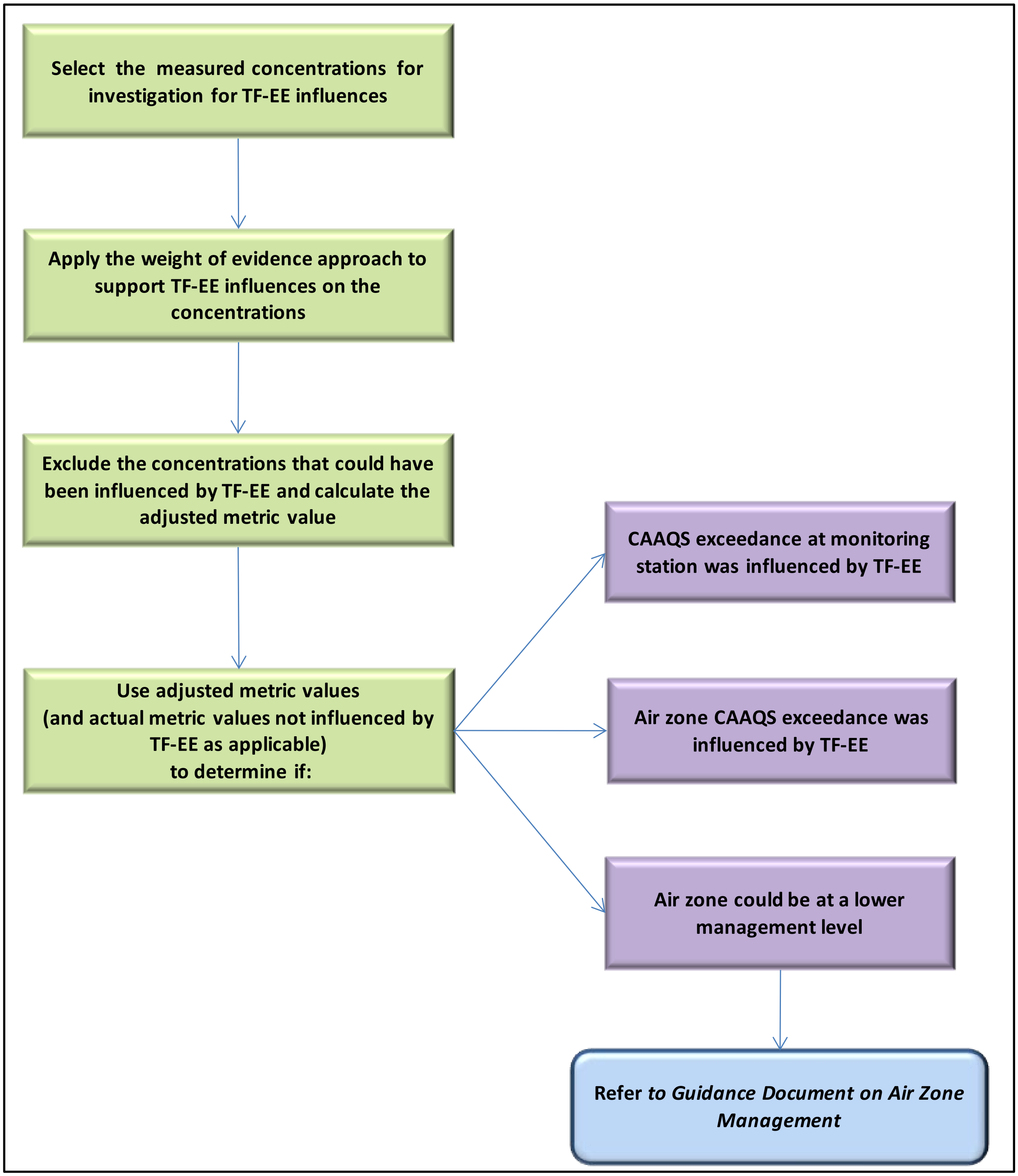
AQMS gives the option to provinces and territories to manage air zones at a resulting lower level after consideration of TF-EE influences. However, jurisdictions should remain cognizant of the fact that the population and the environment are exposed to actual concentrations, not the TF-EE adjusted ones. Therefore, in locations where TF-EE influences are common in every year, to the extent practicable jurisdictions could nonetheless strive to implement measures to try to offset the TF-EE contribution and reduce overall exposure to limit further deterioration in air quality.

Regarding the influence of TFs from one Canadian jurisdiction to another, the affected downwind jurisdiction is encouraged to engage in discussions with the upwind source jurisdiction. The federal government will collaborate with provinces and territories to better understand the flow of air pollution among airsheds and may coordinate the actions required to address international and inter-jurisdictional TF air pollution. For TFs from the United States, the federal government will use the provisions set out under the Canada-United States Air Quality Agreement and lead the discussions in collaboration with the affected Canadian jurisdiction.

8.0 SUMMARY OF THE TRANSBOUNDARY FLOWS AND EXCEPTIONAL EVENTS CONSIDERATION APPROACH

The guidance provided in this report for the consideration of TF-EE influences can be summarised by the high-level schematic in Figure 8-1. The first step is the selection of concentrations to investigate for TF-EE influences. The second step is to apply the WOE approach to support TF-EE influences on the selected concentrations and the third step is the calculation of adjusted metric values following the exclusion of concentrations deemed to be influenced by TF-EE. Analyses for TF-EE influences can be conducted for either all concentrations in the year or only for a sufficient number of them such that their exclusion leads to an adjusted metric value which does not exceed the standard or which corresponds to a lower management level. The adjusted metric values and the actual metric values not influenced by TF-EE are then used to determine the CAAQS achievement status and management level.

Figure 8-1: Outline for the consideration of TF-EE influences.



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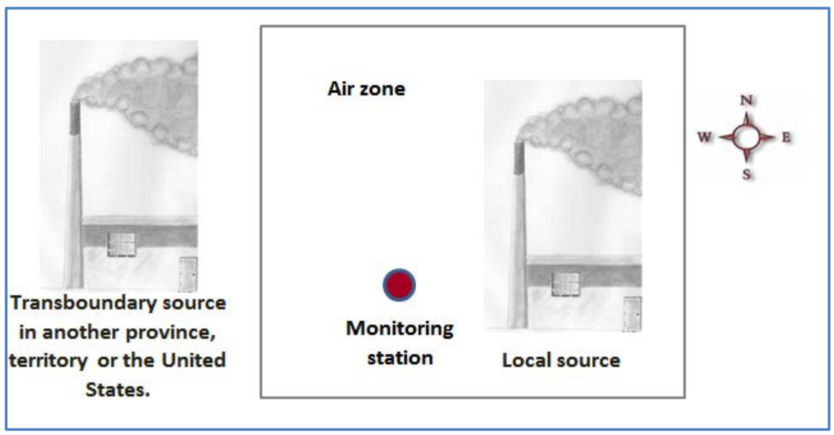
ANNEX – EXAMPLE OF A TRANSBOUNDARY FLOW INFLUENCE ON CANADIAN AMBIANT AIR QUALITY STANDARDS EXCEEDANCE

This Annex provides an example of the 3-step approach for considering TF-EE influences on a CAAQS exceedance. The example is specifically to determine only if a CAAQS exceedance could have been influenced by TF-EE, and not to determine the lowest management level. The example is for the $PM_{2.5}$ 24-hour CAAQS of 27 µg/m^3 for 2020. The statistical form of this standard is the 3-year average of the annual 98th percentile of the daily 24-hour average concentrations. The 3-year period for this example is 2018 to 2020.

This example assumes that the air zone has a single $PM_{2.5}$ CAAQS reporting station. The air zone has a local point source that is located 1 km to the east of the station. There is also a transboundary source located 10 km to west of the station. The diagram to the right provides an indication of the configuration.



The jurisdiction begins by calculating the actual $PM_{2.5}$ 24-hour CAAQS metric value for the 3-year period 2018-2020 following the procedures provided in the guidance document on achievement determination for $PM_{2.5}$. All the information needed for the calculation of the metric value is shown in Table A-1. The actual metric value is 31 µg/m^3 and since it is higher than the 2020 standard of 27 µg/m^3, the air zone does not achieve the 2020 $PM_{2.5}$ 24-hour CAAQS.

The jurisdiction applies next the 3-step process to determine if the exceedance could have been influenced by TF.

Table A-1: Obtaining the actual $PM_{2.5}$ 24-hour CAAQS metric value.

Rank	$PM_{2.5}$ daily 24-hour average concentrations (µg/m³)		
	2018	**2019**	**2020**
Highest	60.7*	45.3	40.1
2nd highest	55.3	41.1	38.3
3rd highest	50.4*	39.7	35.5
4th highest	48.2*	36.3	35.5
5th highest	45.1	36.3	31.1
6th highest	43.1	31.6	26.9
7th highest	41.1	26.1	26.4
8th highest	40.9	26.1	25.3
9th highest	35.6	25.3	24.1
10th highest	26.9	24.1	20.1
⋮	⋮	⋮	⋮
N	351	360	290
Rank of 98th percentile	8th highest	8th highest	6th highest
98th percentile (µg/m³)	40.9	26.1	26.9
3-year average of 98th percentiles (µg/m³)	(40.9 + 26.1 + 26.9) ÷ 3 = 31.3		
Actual metric value (µg/m³)	**31**		

*These are concentrations that the WOE indicates were influenced by TF.

Step 1 – Select the concentrations to investigate for a TF influence

As a reminder, the discussion here applies for the case where the jurisdiction only wants to evaluate if the CAAQS exceedance could have been influenced by TF-EE and not the lowest management level possible. As such, only a minimal number of concentrations need to be evaluated for TF-EE influences.

The jurisdiction decides to first evaluate for TF-EE influences some of the highest concentrations in 2018 since the 98th percentile in 2018 is higher than the standard with nine such concentrations. Given the statistical form of the $PM_{2.5}$ 24-hour CAAQS, the jurisdiction notes that after the exclusion of at least one concentration found to be influenced by TF-EE, N drops from 351 to 350 and with N = 350 the GDAD specifies that the 98th percentile corresponds to the 7th highest concentration. Accordingly, for this example since the 10th highest concentration is less than the standard, the jurisdiction only needs to find at least three concentrations among the eight highest which were likely influenced by TF-EE. With the exclusion of three such concentrations, the 10th highest concentration in 2018 (26.9 µg/m^3) becomes the adjusted 7th highest concentration. Without any prior information, and to keep the number of analyses to a minimum, the jurisdiction therefore decides to apply the WOE sequentially to the eight highest concentrations and stop as soon as three concentrations that could have been influenced by TF-EE are obtained.

Step 2 – Gather evidence to support a TF influence

The jurisdiction begins investigating the highest 24-hour concentration in 2018 of 60.7 µg/m^3 (Table A-1). It starts by finding the date on which this concentration was measured and it finds that it was March 15, 2018. It then conducts several analyses to see if the results converge and point to the transboundary source as the likely main influence on the concentration.

The jurisdiction begins with an analysis of the surface winds for March 14 and 15. Using wind data measured at the nearest airport, it finds that on these days the surface wind was predominantly coming from the west. It next evaluates the upper level winds using data from a rawinsonde that was launched from a location 50 km northwest of the station and it finds that winds were predominantly from the west throughout a layer from the ground up to 1000 m above during both March 14 and 15. The jurisdiction also models a 24-hour forward trajectory starting at 00:00 hour on March 15 at the location of the transboundary source and at a height within the boundary layer. The trajectory goes eastward from the transboundary source and passes over the location of the monitoring station.

Based on the results of the three analyses, the jurisdiction concludes that the WOE indicates that the local source was not likely a main influence on the $PM_{2.5}$ concentrations measured on March 15. Since the monitoring station was downwind of the transboundary source during both March 14 and 15, and not finding any other possible influence, it concludes that this source was likely the major influence on the highest concentrations of 60.7 µg/m^3 measured on March 15.

The jurisdiction next conducts similar analyses for the 2nd, 3rd and 4th highest 24-hour average concentrations. The WOE points to the local source as the main influence for the 2nd highest and to the transboundary source for the 3rd and 4th highest.

Step 3 – Calculate the adjusted metric value

In Step 2 it was determined that the WOE analyses support a TF influence on the highest, the 3rd and 4th highest 24-hour average concentrations shown in Table A-1. The jurisdiction next excludes these concentrations and calculates the adjusted metric value as shown in Table A-2. With the exclusion of the three concentrations, N drops from 351 to 348, and with N= 348 the 98th percentile now corresponds to the 7th highest concentration as specified in the GDAD. The adjusted metric value is 27 μg/m^3 and since it does not exceed the standard, the jurisdiction can claim that the exceedance of the $PM_{2.5}$ 24-hour CAAQS could have been influenced by the transboundary source.

Table A-2: Obtaining the adjusted $PM_{2.5}$ 24-hour CAAQS metric value.

Rank	$PM_{2.5}$ daily 24-hour average concentrations (μg/m^3)		
	2018	**2019**	**2020**
Highest	55.3	45.3	40.1
2nd highest	45.1	41.1	38.3
3rd highest	43.1	39.7	35.5
4th highest	41.1	36.3	35.5
5th highest	40.1	36.3	31.1
6th highest	35.6	31.6	26.9
7th highest	26.9	26.1	26.4
8th highest	25.4	26.1	25.3
⁞	⁞	⁞	⁞
N	348	360	280
Rank of 98th percentile	7th highest	8th highest	6th highest
98th percentile (μg/m^3)	26.9	26.1	26.9
3-year average of 98th percentiles (μg/m^3)	(26.9 + 26.1 + 26.9) ÷ 3 = 26.6		
Adjusted metric value (μg/m^3)	**(26.9 + 26.1 + 26.9) ÷ 3 = 27**		

Discussion

For the example above, if none of the eight highest concentrations in 2018 were influenced by TF-EE, the jurisdiction could sequentially evaluate for TF-EE some of the concentrations in 2019 and 2020 beginning with the higher ones.

The objective of these evaluations would be to exclude concentrations such that the resulting adjusted annual 98th percentiles lead to a 3-year average (which is the adjusted metric value) that does not exceed the standard. For example, if in 2018 there are no concentrations influenced by TF-EE, the adjusted metric value can nonetheless be lowered if either or both of the adjusted 98th percentiles in 2019 and 2020 are lower than their actual values. For example, after consideration of TF-EE influences the adjusted 98th percentiles drop to 15.1 μg/m^3 in 2019 and 20.5 in 2020. With these adjusted 98th percentile the adjusted metric value is now 26 μg/m^3 [(40.9 + 15.1 + 20.5) ÷ 3], which is below the standard.