Canada-Wide Standards Achievement In the Atlantic Region: Model Results for New Brunswick Part II

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ABSTRACT

In support of provincial jurisdiction implementation plans for achievement of Canada-Wide Standards (CWS) for fine Particulate Matter ($PM_{2.5}$) and Ozone, the contribution of trans-boundary transport to pollutant concentrations in Atlantic Canada was re-assessed using the Canadian Hemispheric and Regional Ozone and NO_x System (CHRONOS) Chemical Transport Model with updated anthropogenic emission rates. For an episode in August 2001, when the CWS for $PM_{2.5}$ and Ozone was exceeded in Atlantic Canada, the relative contributions of US and Canadian anthropogenic emissions to constituent concentrations were simulated at monitoring sites in the region. It was determined that trans-boundary transport of ozone and its precursors was the dominant contributor to high ozone levels during this episode of poor air quality. The contribution by New Brunswick anthropogenic emissions to the modeled daily maximum 8 hour average ozone concentration at Saint John on 3 exceedance days during August 2001 was found to average 3%. Local emission reductions alone could not be expected to have achieved the Canada-Wide Standard for Ozone in the urban core of Saint John in this case. On days when the CWS was not exceeded during the modeled period, New Brunswick anthropogenic emissions were found to contribute an average of 8% to the ozone levels at 3 Saint John sites. Reductions to anthropogenic emissions at the provincial level could be expected to have a greater impact on air quality in areas downwind of the urban fringe. New Brunswick's contribution to the model's daily maximum 8 hour average ozone at Norton NB, a rural site downwind of Saint John, was found to average 16% on the days when the CWS for Ozone was exceeded at that site during this period of August 2001 and 22% on non-exceedance days. Anthropogenic emissions of precursors and primary fine particulate originating in New Brunswick were found to contribute a higher percentage to local concentrations of $PM_{2.5}$, particularly on days when the 24 hour average concentrations were below the CWS during the modeled period. At the Saint John – Forest Hills site, where the CWS for $PM_{2.5}$ was exceeded on August 10, New Brunswick's contribution to the 24 hour average concentration, as simulated by CHRONOS, was found to be 5% on that day. On the other days during the modeled period, when concentrations were below the CWS, New Brunswick's contribution to fine particulate concentration averaged 54% at the Forest Hills site. Reductions to emissions of primary fine particulate and precursors to $PM_{2.5}$ by provincial jurisdictions could therefore be expected to have a greater impact on regional air quality. Model fine particulate concentrations do not always compare favourably with measured values, so the absolute value of any anticipated reductions are uncertain for PM given current Chemical Transport Models. The contribution of anthropogenic emissions from the various jurisdictions within the model domain was found to vary widely from day to day as a function of meteorology. Since there was only one day in this modeled period when the CWS for PM was exceeded, it is not possible to quantify the amount of reduction in primary and precursor emissions required by any one jurisdiction to meet the Canada-Wide Standard for $PM_{2.5}$ in all cases.

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INTRODUCTION

Certain meteorological patterns have been recognized as being associated with air pollution episodes in Atlantic Canada. Stable atmospheric conditions trap emitted primary and precursor pollutants near the earth's surface, leading to higher pollutant concentrations and more reactive chemistry (Seinfeld and Pandis 1998). Wind speed and direction influence the transport of precursors to ozone and particulate matter (PM) formation toward the Atlantic Region from emission sources, such as southwesterly trajectories from the northeastern United States, while light winds allow reduced mixing and the build-up of locally emitted pollutants. Other factors such as sunlight, high temperatures and high humidity favour an increase in photolysis, emission of biogenic isoprene, evaporative emissions of volatile organic compounds (VOCs) and the thermal decomposition of reservoirs of nitrogen oxides (NO_x) such as peroxyacetyl nitrate (PAN) (Dempsey 2005). Stable meteorological conditions, low wind speeds and high temperatures are characteristic of high pressure systems in summer, when the majority of smog episodes occur in north-eastern North America (Brook and Johnson 2000).

The current Canadian ambient air quality objective for ground level ozone was established in 1976 under Canada's Clean Air Act and confirmed under the 1988 Canadian Environmental Protection Act (CEPA). Based on the scientific information available at the time, the Canadian national objective for an acceptable level of ozone (1 hour averaging time) was set at 82 parts per billion (ppb). National ambient air quality objectives exist for Total Suspended Particulate (TSP) but there are no current acceptable levels defined for respirable particles, PM_{10} (airborne particles $\leq$10 μm in diameter) or fine particles, $PM_{2.5}$ ($\leq$2.5 μm). There are some provincial standards in place for PM_{10}. British Columbia established a standard for 24 hour average PM_{10} of 50 μgm^{-3} in 1995. Newfoundland and Labrador's permissible level for 24 hour average $PM_{2.5}$ concentration is 25 μgm^{-3}. In the Quebec and Atlantic Regions, Environment Canada's threshold for issuing an Air Quality Advisory is a 3 hour average $PM_{2.5}$ concentration in excess of 35 μgm^{-3} (Gabig *et al*. 2002, Henderson 2006).

The rationale for Canada-Wide Standards (CWS) for Particulate Matter (PM) and Ozone is to minimize risks to human health and the environment associated with these pollutants. The fine fraction of PM, $PM_{2.5}$, has been recognized as having the greater effect on human health. Achievement of the CWS for $PM_{2.5}$ was defined as the 24 hour (midnight to midnight) average $PM_{2.5}$ concentration $\leq$30 μgm^{-3} by the year 2010. For a given reporting area, the standard would be based on the 98^{th} percentile ambient measurement annually, averaged over 3 consecutive years. For ozone, the CWS was defined as the 8 hour average ozone concentration $\leq$65 ppb by 2010. Achievement was to be based on the annual 4^{th} highest daily measurement, averaged over 3 consecutive years. There are also provisions for Continuous Improvement (CI) and Keeping Clean Areas Clean (KCAC) (CCME 2002).

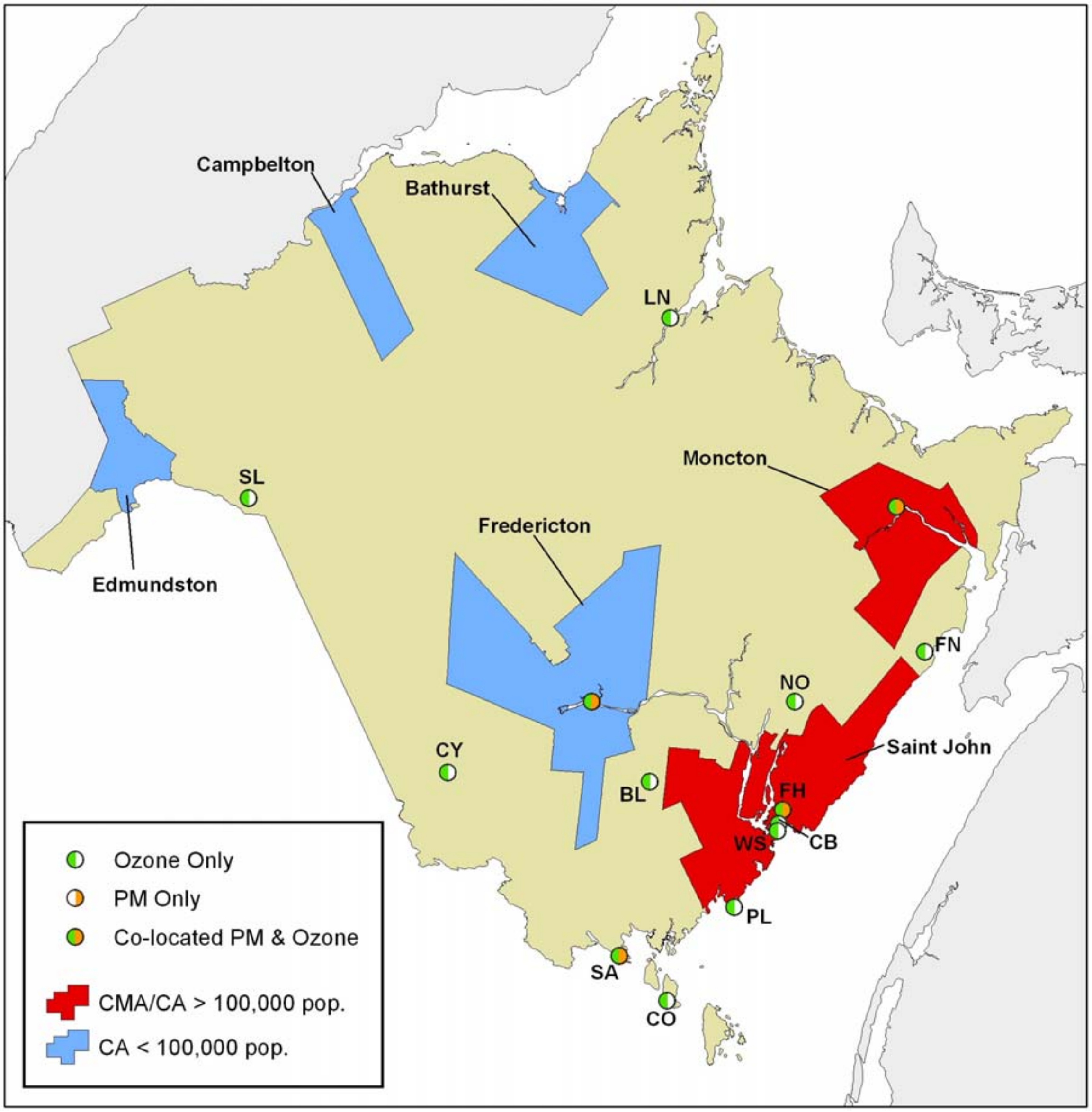

Figure 1. Census Metropolitan Areas and Census Agglomerations in New Brunswick

(NAPS Network Monitoring sites in 2001: Blissville (BL); Customs Building - Saint John (CB); Campobello Island (CO); Canterbury (CY); Saint John-Forest Hills (FH); Fundy National Park (FN); Fredericton; Lower Newcastle (LN); Moncton; Norton (NO); Pt. Lepreau (PL); St. Andrews (SA); St. Leonard (SL); West Side-Saint John (WS))

Jurisdictions under CWS are federal, provincial and territorial governments. Jurisdictions are required to report on CWS achievement for population centres of 100,000 or more. Census Metropolitan Areas (CMAs), as established by Statistics Canada, are the units used to identify these communities. CMAs include the commuter shed surrounding an urban core, which consists of an urbanized fringe and a rural fringe. Jurisdictions may also report on CWS achievement for smaller urban centres with population of at least 10,000, which are referred to as Census Agglomerations (CA). In New Brunswick, based on the 2001 Census, there are two reporting areas: the CMA of Saint John and the CA of Moncton (CCME 2002) (Figure 1). Other CAs in New Brunswick are shown in Table 1.

Table 1. Census Metropolitan Areas and Census Agglomerations in New Brunswick

Census Metropolitan Areas (CMA)	Census Agglomerations (CA)
Saint John	Moncton
	Fredericton
	Bathurst
	Campbellton
	Edmunston

Each air quality monitoring location in New Brunswick has been classified as either rural or urban. The National Air Pollutant Surveillance Network (NAPS) classification of each site operating in New Brunswick in 2001 is shown in Table 2.

Table 2. NAPS Monitoring Stations in New Brunswick in 2001

STN ID	LOCATION	ADDRESS	LAT	LONG	Loc CLASS
040103	**Fredericton, NB**	Aberdeen St.	45.96	-66.65	Urban Commercial
040203	**Saint John, NB**	Forest Hills	45.31	-66.01	Urban Residential
040206	Saint John, NB	Customs Bldg	45.27	-66.06	Urban Commercial
040207	Saint John, NB	West Side	45.25	-66.08	Urban Residential
040302	**Moncton, NB**	Thanet Street	46.10	-64.79	Urban Residential
040401	Fundy Nat'l Park	Hastings Tower	45.59	-65.00	Rural Undeveloped
040501	Pt. Lepreau, NB	Charlotte County	45.07	-66.45	Rural Undeveloped
040601	Blissville, NB	Sunbury County	45.61	-66.56	Rural Undeveloped
040701	Norton, NB	Kings County	45.64	-65.71	Rural Undeveloped
040801	Canterbury, NB	Main Street	45.95	-67.48	Rural Undeveloped
040901	**St. Andrews, NB**	Huntsman Marine	45.09	-67.08	Rural Undeveloped
041001	Campobello, NB	Campobello Is.	44.87	-66.96	Rural Undeveloped
041101	St. Leonard, NB	Municipal Airport	47.15	-67.83	Rural Undeveloped
041201	Lower Newcastle	Route 11 Highway	47.08	-65.40	Rural Undeveloped

Note: Bold type indicates sites where both ozone and $PM_{2.5}$ were measured in 2001. St. Andrews was the only PM monitoring site classified as rural in 2001. (NAPS 2001)

In a previous study (Farrell 2005), zero-out model scenarios were completed for episodes when the Canada-Wide Standards (CWS) for $PM_{2.5}$ and Ozone were exceeded in the Atlantic Region in 2001. In that study, anthropogenic emission rates were based on the 1990 Canadian Criteria Air Contaminant (CAC) emission inventories with growth factors applied for extrapolation to 1995. US emission rates had been based on a 1996 National Emission Inventory (NEI). Updated anthropogenic emission inventories for Canada and the US became available since that study was completed. Further model scenarios were completed on an episode of poor air quality in August 2001 using anthropogenic emission rates from the 2000 Canadian CAC inventory and the 2001 US NEI.

The overall objective of this study is to support jurisdictional implementation planning and determination of the appropriate level of sectoral emission reductions required for CWS achievement for $PM_{2.5}$ and Ozone in the Atlantic Region.

METHODOLOGY

Model Description

Global Environmental Multi-scale Meteorological Model

The meteorological fields required for input to the Chemical Transport Model (CTM) were obtained from the Meteorological Service of Canada's Global Environmental Multi-scale (GEM) model. The version of the model employed was GEMDM3.1.1, where DM stands for Distributed Memory. The model domain comprised all of Canada and the continental US with 270 by 353 grid points and a horizontal resolution of 24 km. This version of the model had 28 vertical pressure levels with the first 7 in the boundary layer; the top was at 10 millibars (mb). The model time step was 450 seconds (7.5 minutes).

The GEMDM model was initialized using an objective analysis from 1800 UTC each day of the modeled period. The model integrated for 30 hours from initialization and the first 6 hours were discarded as this was considered spin-up time for the meteorological model. The resultant output files were interpolated horizontally and vertically to match the CTM grid.

Canadian Meteorological Centre Trajectory Model

The Canadian Meteorological Centre (CMC) Trajectory Model computes the path followed by an air parcel transported by the wind vector, as given by the GEM meteorological model, to a receptor (D'Amours and Pagé 2001). Trajectories at the 1000, 950 and 925 mb levels have been shown to be suitable to trace the path of an air parcel back to the source region of primary pollutants and precursor gases (Brook and Johnson 2004).

Canadian Hemispheric and Regional Ozone and NOx System (CHRONOS)

CHRONOS is a comprehensive air quality model containing a full description of atmospheric chemistry and meteorological processes. The model utilizes output from the atmospheric model GEM for advection and diffusion and employs the ADOM photochemistry scheme (Pudykiewicz *et al*. 1997). CHRONOS was run on a 21 km 200 x 105 horizontal grid (Figure 1), which included most of the Atlantic Region, Quebec and southern Ontario, and much of the Northeastern and Midwestern US. This was a subset of the CHRONOS North American operational grid. There were 24 vertical levels topped at 6 km; 15 levels were in the planetary boundary layer below 1500 metres. The model time step was one hour.

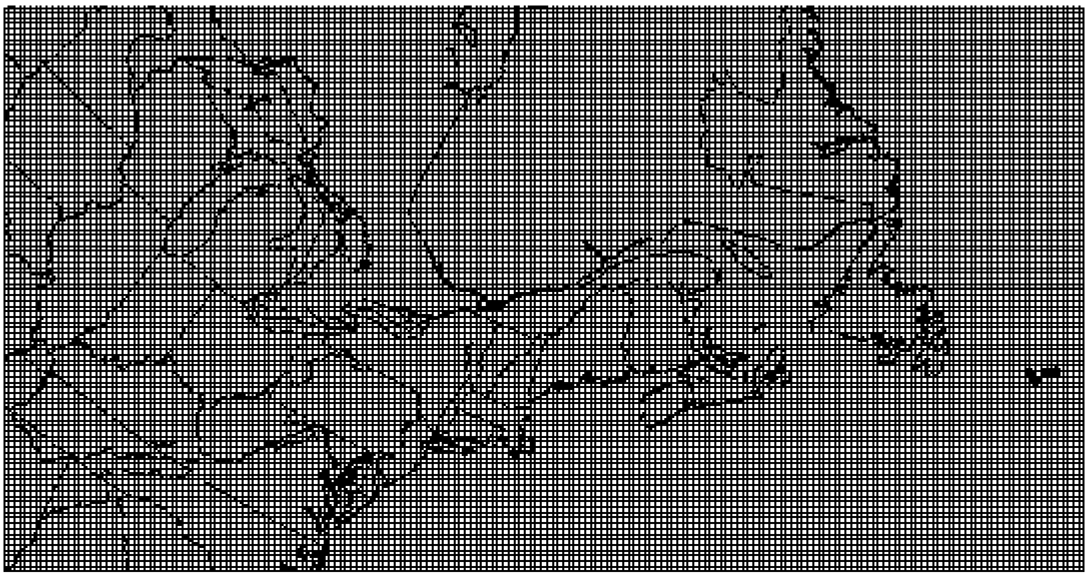

Figure 2. CHRONOS Model Domain: 200 x 105 grid points at 21 km resolution.

The CHRONOS Model was integrated over the period July 31 through August 13, 2001. The first 48 hours of each modeled period were considered spin up time for the CTM, allowing background levels to accumulate after a cold start of the chemistry module. Model output during the spin up phase are not considered to be reliable, therefore the results shown commence August 2. The predictions of $PM_{2.5}$ and ozone at the model's surface level were linearly interpolated to the position of the monitoring site given by their latitude and longitude in the NAPS database (Table 2).

Emissions

Precursors to ozone formation include nitrogen oxides (nitric oxide (NO) and nitrogen dioxide (NO_2), collectively referred to as NO_x) and volatile organic compounds (VOCs). Precursors to $PM_{2.5}$ formation include NO_x, sulphur dioxide (SO_2), VOCs and ammonia (NH_3). Anthropogenic emission rates used by the CHRONOS model were based on North American inventories of 7 Criteria Air Contaminants (CAC), which contain annual emissions of SO_2, NO_x, VOCs, $PM_{2.5}$, PM_{10} and carbon monoxide (CO). Canadian emissions were from the 2000 CAC inventory, by province and territory. US emissions were based on the 2001 NEI, containing CAC emissions by state and county in the

United States. Emissions were processed for use in the models by the Sparse Matrix Operating Kernel Emissions (SMOKE) Modeling System (CEMPD 2005).

Biogenic emissions were computed using the Biogenic Emissions Inventory System (BEIS-II) algorithm (Scholtz *et al*. 1999), as in the 2005 study. Isoprene emission rates were calculated by BEIS-II using emission factors for 18 tree species in a coarse land-use inventory with no correction for temperature. Over-prediction of isoprene concentrations by BEIS-II has been acknowledged (V. Bouchet, personal communication, 30 March 2005).

Scenarios

To determine the contribution of local, regional and trans-boundary anthropogenic emissions to the concentration of ground level ozone and $PM_{2.5}$ for selected cases when the CWS was exceeded in the Atlantic Region, the CHRONOS model was used to simulate ambient air quality in the Atlantic Region. It was assumed that the concentration of each species of interest was the sum of local, inter-provincial and trans-boundary anthropogenic source components plus the natural background concentration due to biogenic sources. In this case, trans-boundary emissions refer to those originating in the United States, as that was the only non-Canadian jurisdiction within the model's domain.

To determine the Canadian-sourced and trans-boundary components, the following 5 emission scenarios were used in modeling each case:

a) the "New Brunswick emissions only" scenario had anthropogenic emissions within New Brunswick at levels in the 2000 Canadian CAC inventory and all anthropogenic emission sources outside of New Brunswick set to zero (hence a "zero-out" scenario)
b) a "Regional" scenario had all anthropogenic emissions originating in Nova Scotia, Prince Edward Island, Newfoundland and Labrador at levels in the existing inventory, while all anthropogenic emissions originating in the US, Quebec, Ontario and New Brunswick were set to zero
c) the "Rest of Canada" scenario had anthropogenic emissions originating in Quebec and Ontario at levels in the existing inventory and all other anthropogenic emission sources set to zero
d) the "Trans-boundary" (or "US only") scenario had US anthropogenic emission sources at the level in the 2001 NEI, while all Canadian anthropogenic emissions were set to zero
e) the "Background" scenario had all Canadian and US anthropogenic emissions set to zero

The technique used to zero-out the anthropogenic emissions from a certain jurisdiction was accomplished by setting a multiplication factor for that jurisdiction to zero. The ST field within CHRONOS consists of 69 unique regions including each province and state within the entire North American domain. Setting a jurisdiction's assigned a number to zero in the CHRONOS configuration files (*chronos_erf_cfgs* and *chronos_erfpm_cfgs*) effectively turned off the mobile, non-mobile, major and minor point emission sources attributed to that jurisdiction in the emission files.

The results of each of the zero-out scenarios had to have the model's background concentration (as determined by the "Background" scenario) subtracted from the model results since all these other scenarios would have the contribution from biogenic activity included.

Normal natural background levels of ozone have been reported to be in the range of 30 to 40 ppb (CCME 1997). Background ozone concentrations due to biogenic sources using the model's "Background" scenario ranged from a low of 13 ppb at Norton on August 10, up to 42 ppb at Campobello Island on August 2. Biogenic-sourced ozone was shown contribute up to 90% of the total model ozone at some New Brunswick rural sites on good air quality days (Appendix B, Figures B-1 to B-9).

Expected background concentrations of $PM_{2.5}$ on an annual or long term basis has been reported to be in the range 1 to 5 μgm^{-3} for remote sites in North America. The range of background concentrations on a shorter term basis is much broader given the episodic nature of natural events such as wildfires and dust storms, which can result in short-term PM levels comparable to those in polluted urban environments. Between 1992 and 1995, three rural Canadian sites (Kejimkujik, Sutton and Egbert) recorded mean 24 hour $PM_{2.5}$ concentrations of 7.0, 7.7 and 10.5 μgm^{-3} respectively (Health Canada and Environment Canada 1998). Model background concentrations of $PM_{2.5}$ were found to be less than 2 μgm^{-3} in the August 2001 case.

The resultant concentrations from the "New Brunswick only", "Regional", "Rest of Canada", "Trans-boundary" (all with the 24 hour average biogenic-sourced concentrations removed) and the "Background" scenarios at each monitoring location in the Atlantic Region were used to determine the relative contribution of anthropogenic emissions within each jurisdictional grouping to model ozone and $PM_{2.5}$ concentrations. The sum of the 5 scenarios was compared to ambient concentrations measured at each site in the Atlantic Region and was used to calculate the percentage of the total model concentration, thus giving the relative contribution of each jurisdictional grouping to pollutant levels at each site. For ozone, each day's maximum of the 8 hour running average model concentration was compared to the maximum 8 hour average measured value for that site. For $PM_{2.5}$, the average 24 hour concentration (midnight to midnight) was used for the comparisons.

This representation of ambient concentration as a summation of all contributing jurisdictions can only be considered as a conceptual approximation for comparison purposes and cannot take into account all non-linear effects (Morneau 2005). It was accepted that these model results are not additive. It was assumed, however, that relative contributions, according to the model, could be attributed by this method.

Description of Episodes

August 2001

Elevated levels of ground level ozone were widespread across the Atlantic Region on August 2, 3, 10 and 11, 2001. The CWS for $PM_{2.5}$ was exceeded at the Saint John – Forest Hills site on August 10.

On August 1, 2001 a large ridge of high pressure lay over much of the northeastern US, southern Ontario and southern Quebec. A cold front extended from James Bay to west of the Great Lakes. Afternoon temperatures in the warm sector and under the area of high pressure ranged from 28 to 32^{o}C. On August 2, as the ridge was pushed toward the southeast, a weak west to southwest flow developed over the Maritimes. The front stalled over the Great Lakes and a weak trough of low pressure formed along the Eastern Seaboard of the US. Afternoon temperatures remained in the 27 to 33^{o}C range in the warm sector and a light southwest flow persisted across Atlantic Canada. On the morning of August 3, the cold front crossed New Brunswick, Nova Scotia and western Newfoundland. A weak frontal zone remained across Nova Scotia and south of Newfoundland for the next 48 hours. By the evening of August 5, a weak ridge of high pressure became re-established over the northeastern US and southern Ontario. Under light winds associated with the ridge, temperatures had risen to 28 to 30^{o}C. The pattern repeated itself as a cold front approached from west of the Great Lakes on August 6. The ridge was pushed southeast over West Virginia and a southwest flow developed over southern Quebec and Ontario. Afternoon temperatures were in the low 30s. By evening on the 6th, the ridge was weakening between a trough of low pressure in the vicinity of Sault Ste. Marie and Tropical Depression Barry, which was weakening over the southern Mississippi River Valley. At the same time, a light southwest flow was developing across Atlantic Canada. The southwesterlies increased to moderate to strong as the trough moved over the Bay of Fundy and a cold front approached northern New Brunswick on the afternoon of the 7th. By the next morning, the cold front was lying south of Nova Scotia and a northwest flow behind the front brought cooler temperatures to the region. The pattern started re-establishing itself by the afternoon of August 9 with a cold front near Sault Ste. Marie and a trough of low pressure along the Eastern Seaboard of the US. A light south to southwest flow saw temperatures rise over New England and central New Brunswick to between 32 and 36^{o}C. The south to southwest flow across the Maritimes increased as the cold front crossed Lake Ontario and the St. Lawrence River Valley. The front reached northern NB by the afternoon of August 10. Temperatures throughout New England, the Maritimes and western Newfoundland reached 30 to 33^{o}C. By the next morning, the cold front had passed to lie south of Atlantic Canada, bringing a light to moderate west to northwest circulation behind the front, marking the end of the episode.

The meteorological pattern preceding the event, whereby the large ridge of high pressure produced stagnant conditions, was conducive to the build-up of precursor pollutants over well known source regions of the northeastern US, southern Ontario and southern Quebec. High afternoon temperatures under the area of high pressure would have favoured ozone production through increased photolysis, isoprene emission rates and evaporation of hydrocarbons (Dempsey 2005). As the ridge was pushed toward the southeast by the frontal trough developing over the central part of the continent, a weak west to southwest flow developed over the Maritimes. The southwesterlies increased to moderate to strong with the approach of the front, bringing precursor pollutants toward the Atlantic Region. Back trajectories for 72 hours preceding the exceedance of the CWS for $PM_{2.5}$ at the Saint John – Forest Hills site are shown in Figure 3.

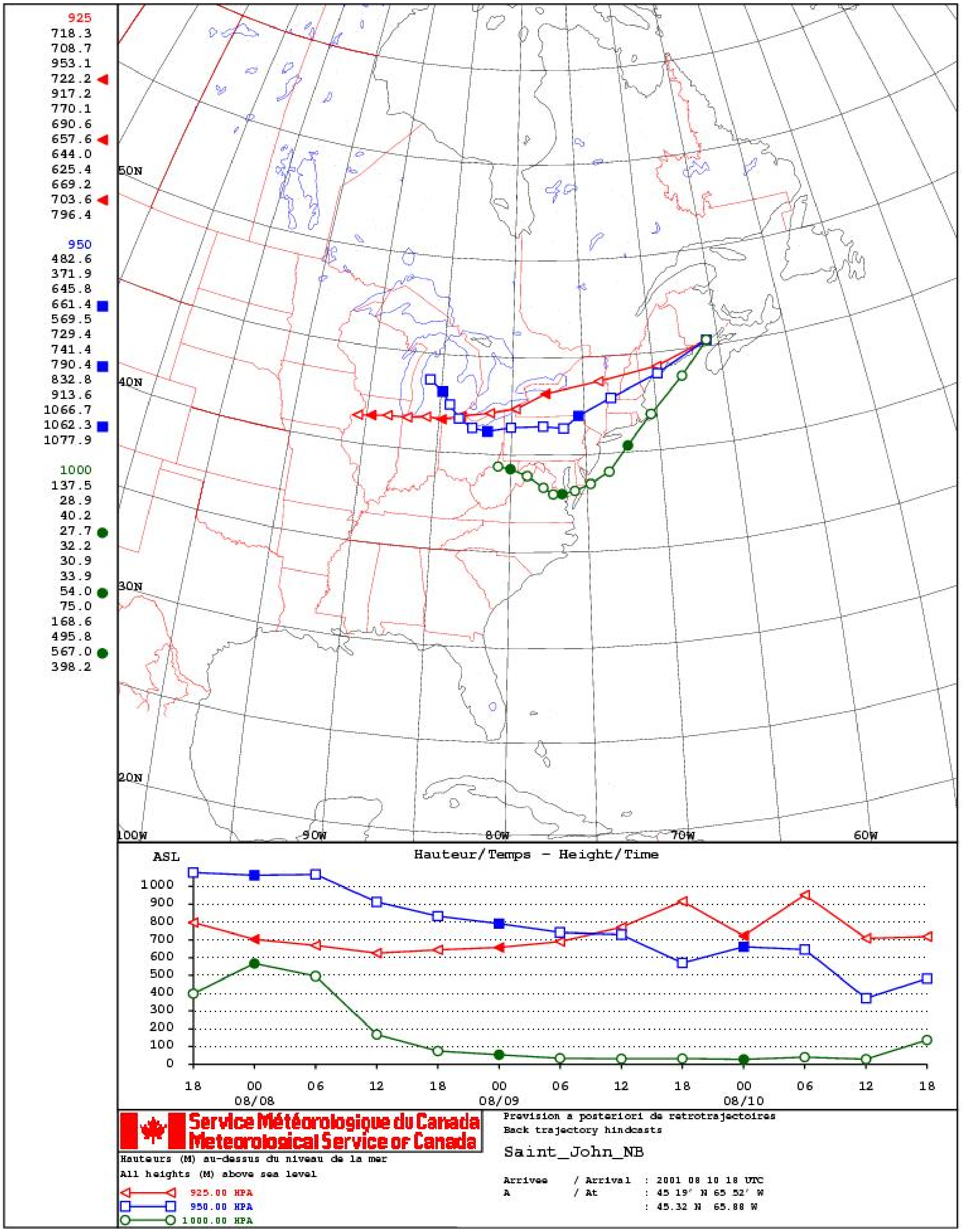

Figure 3. 72 Hour Back trajectories arriving at Saint John NB 1800UTC 10 August 2001

RESULTS AND DISCUSSION

Ozone

Figure 4 illustrates the CHRONOS model scenario results for the West Side - Saint John monitoring site where the CWS for Ozone was exceeded during the first half of August 2001. The sum of each of the 5 model scenarios (with the daily model background values removed) was compared to the measured ambient ozone at that site. Figure 5 shows the relative contributions of each of the 4 jurisdictional groupings and natural background as a percentage of the total of the 5 scenarios.

Similar CHRONOS model scenario results for all New Brunswick monitoring sites where the CWS for Ozone was exceeded in August 2001 are shown in Appendices A and B.

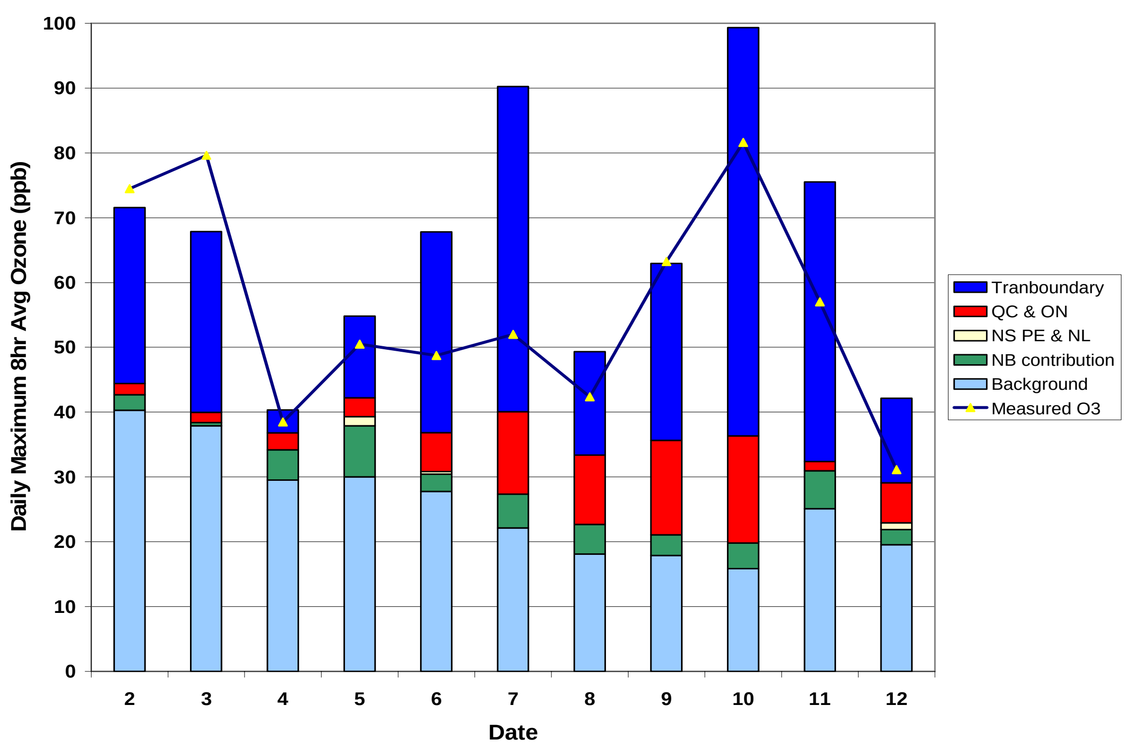

Figure 4. Relative Contributions to CHRONOS Model Ground Level Ozone at West Side - Saint John NB 2-12 Aug 2001

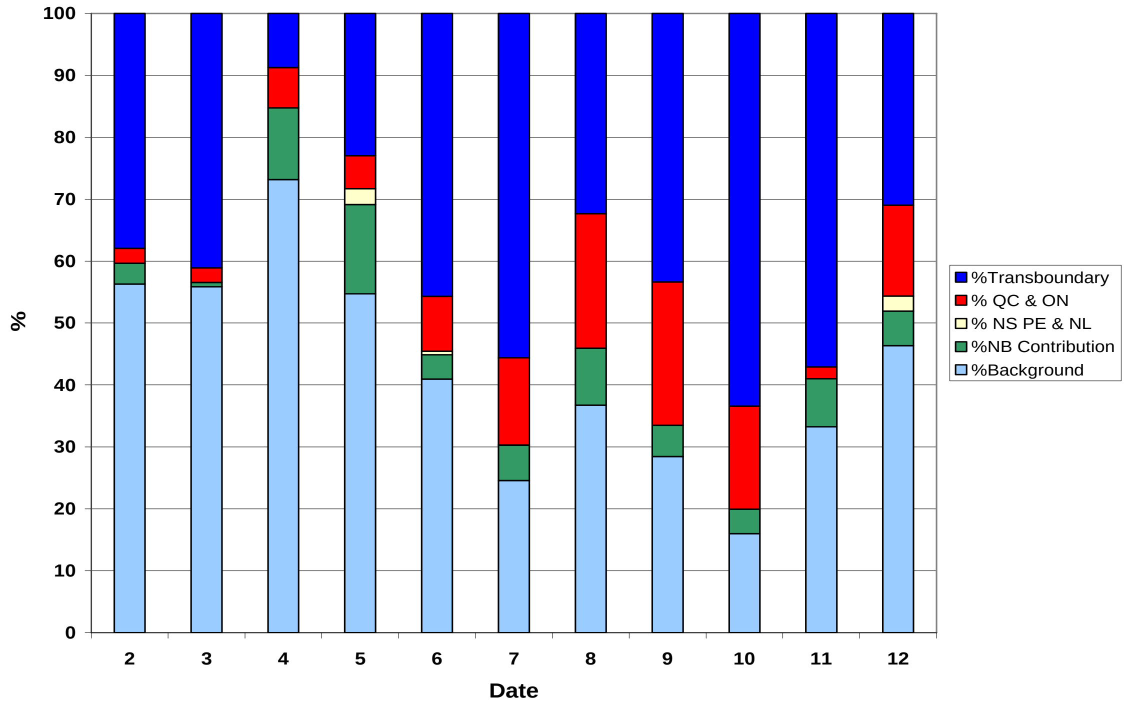

Figure 5. Percent Contribution to CHRONOS Model Ground Level Ozone at West Side - Saint John NB 2-12 August 2001

As seen in Figure 5, the natural background accounted for more that 70% of the model ground level ozone on some of the better air quality days, such as on August 4, at the urban residential West Side - Saint John site. Up to 90% of the model's ozone was attributed to biogenic sources at rural undeveloped sites on some of better air quality days, such as at St. Leonard on August 4 and 5 (Figure 6).

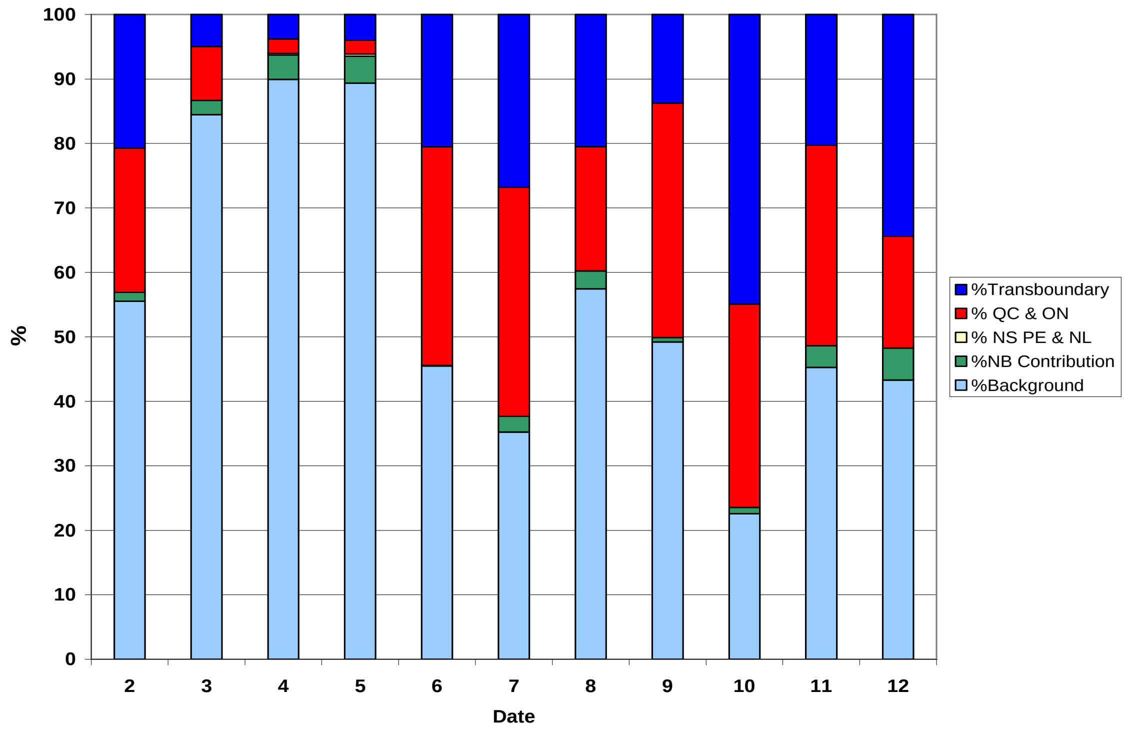

Figure 6. Percent Contribution to CHRONOS Model Ground Level Ozone at St. Leonard NB 2-12 August 2001

Table 3 summarizes the average percent contribution from various jurisdictional groupings to the CHRONOS model ground level ozone on days when the CWS for Ozone was exceeded, as determined by the scenario runs.

Since the percent contribution varied day to day, as a function of meteorological conditions, Table 4 shows the percent contributions of emissions from three of the jurisdictional groupings to the maximum 8 hour average ozone, as determined by the CHRONOS model, for each day the CWS of 65 ppb was exceeded at New Brunswick monitoring sites.

Table 3. Average Percent Contribution to CHRONOS Model Ground Level Ozone at New Brunswick Sites when Daily Maximum 8-hour Average Ozone > 65 ppb 2-12 August 2001

Station	**Average % Contribution to Ozone**				
Urban Sites	**Background**	**NB**	**NS PE & NL**	**QC&ON**	**T-B**
Saint John-West Side	*43*	*3*	*0*	*7*	*47*
Saint John-Customs	*35*	*3*	*0*	*9*	*52*
Rural Sites					
St.Leonard	*70*	*2*	*0*	*15*	*13*
Blissville	*45*	*6*	*0*	*8*	*41*
Campobello	*42*	*0*	*0*	*7*	*51*
St.Andrews	*53*	*0*	*0*	*3*	*44*
Pt.Lepreau	*35*	*0*	*0*	*10*	*54*
Norton	*39*	*16*	*0*	*7*	*38*
Fundy	*16*	*0*	*0.2*	*18*	*66*
Averages					
Urban NB Sites (N=2)	*39*	*3*	*0*	*8*	*50*
Rural NB Sites (N=7)	*43*	*3*	*0*	*10*	*44*
All NB Sites (N=9)	**42**	**3**	**0.02**	**9**	**45**

Table 4. Percent Contribution of Anthropogenic Emission Sources at New Brunswick Sites on Days when the Maximum 8 hour Average Ozone > 65 ppb.

%Contribution	**New Brunswick**			**Quebec & Ontario**			**Trans-boundary**		
Station	**2Aug**	**3Aug**	**10Aug**	**2Aug**	**3Aug**	**10Aug**	**2Aug**	**3Aug**	**10Aug**
Urban Sites									
Saint John -WS	**3**	**1**	**4**	**2**	**2**	**17**	**38**	**41**	**63**
Saint John - CB		**2**	**4**		**2**	**16**		**40**	**63**
Rural Sites									
St.Leonard	**1**	**2**		**22**	**8**		**21**	**5**	
Blissville	**3**	**12**	**2**	**5**	**3**	**16**	**34**	**26**	**64**
Campobello	**0.1**	**0**	**0**	**3**	**2**	**18**	**42**	**46**	**65**
St.Andrews		**0**			**3**			**44**	
Pt.Lepreau		**0**	**0**		**2**	**18**		**44**	**65**
Norton	**17**	**14**	**18**	**4**	**2**	**14**	**29**	**28**	**55**
Fundy			**0**			**18**			**66**
Averages									
Urban (N=2)	**3**	**2**	**4**	**2**	**2**	**17**	**38**	**41**	**63**
Rural **(**N=7)	**5**	**5**	**4**	**9**	**3**	**17**	**31**	**32**	**63**
All Sites (N=9)	**5**	**4**	**4**	**7**	**3**	**17**	**33**	**33**	**63**

Table 5 shows the percent New Brunswick contribution to the maximum 8 hour average ozone, as determined by the CHRONOS model, for each day the CWS of 65 ppb was exceeded at New Brunswick monitoring sites. Applying this daily percentage contribution as a reduction to the measured daily maximum 8 hour average ozone, a resultant value with zero local anthropogenic emissions (i.e. No New Brunswick) was determined.

Table 5. Exceedances of the Canada-Wide Standard for Ozone: Daily Measured Maximum 8 Hour Average Ozone and Percent Reduction Expected by CHRONOS Model with No New Brunswick Anthropogenic Emissions

Station	**Date**	**Max 8hr Avg Measured O_3**	**% NB contribution**	**Resultant O_3**
Urban Sites				
Saint John – West Side	2 Aug	*74*	*3*	**72**
	3 Aug	*80*	*0.7*	**79**
	10 Aug	*82*	*4*	**78**
Saint John – Customs	3 Aug	*66*	*2*	*64*
	10 Aug	*76*	*4*	**72**
Rural Sites				
St. Leonard	2 Aug	*66* ppb	*1*	*65* ppb
	3 Aug	*68*	*2*	**66**
Campobello	2 Aug	*75*	*0.1*	**75**
	3 Aug	*72*	*0.1*	**72**
	10 Aug	*66*	*0*	**66**
St. Andrews	3 Aug	*69*	*0*	**69**
Pt. Lepreau	3 Aug	*72*	*0*	**72**
	10 Aug	*70*	*0*	**70**
Blissville	2 Aug	*69*	*3*	**67**
	3 Aug	*77*	*12*	*64*
	10 Aug	*68*	*2*	**66**
Norton	2 Aug	*68*	*17*	*57*
	3 Aug	*67*	*14*	*57*
	10 Aug	*77*	*18*	*63*
Fundy National Park	10 Aug	*77*	*0*	**77**

Bold Type indicates where the CWS for Ozone (Maximum 8 hour average $\leq$ 65 ppb) would not be met under the “No New Brunswick Anthropogenic Emissions” scenario

This result indicates that even with no local anthropogenic emissions, the CWS for Ozone would still not be met at all sites on all exceedance days. With an average New Brunswick contribution of 16% over the three exceedance days during August 2001, a reduction in NB anthropogenic emissions could be expected to have a greater impact at Norton, a rural undeveloped area downwind of Saint John, than within the urban core (Figure 7).

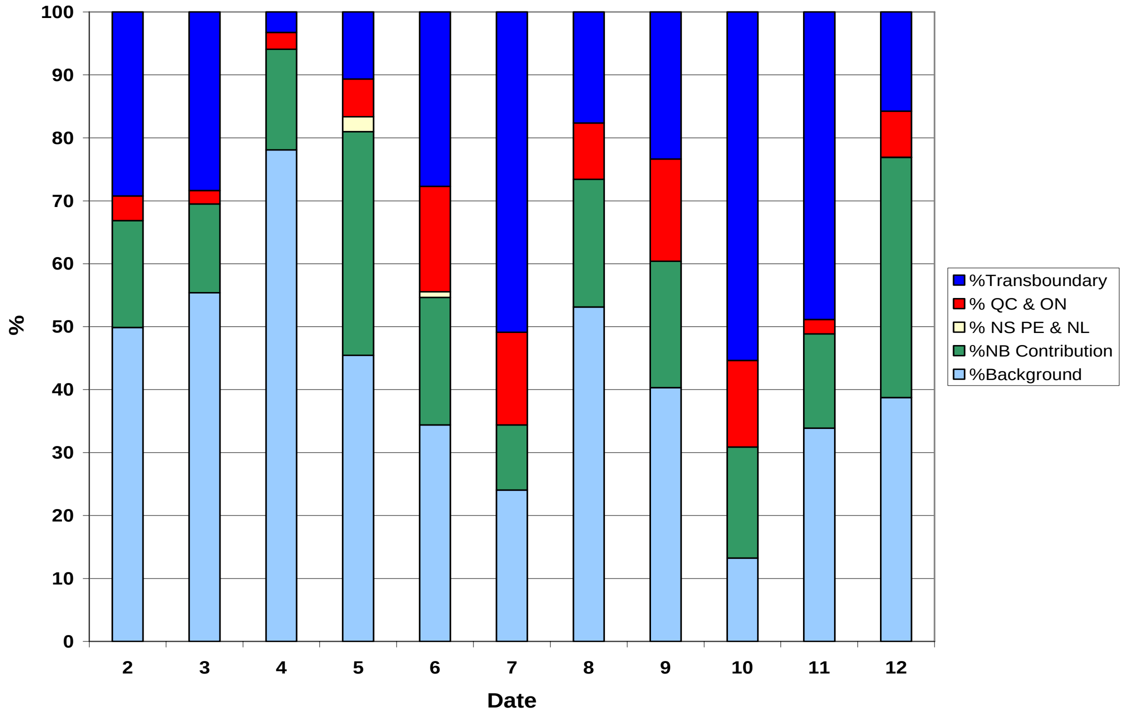

Figure 7. Percent Contribution to CHRONOS Model Ground Level Ozone at Norton NB 2-12 August 2001

$PM_{2.5}$

Figure 8 demonstrates the CHRONOS model scenario results for the Saint John – Forest Hills monitoring site where the CWS for $PM_{2.5}$ was exceeded on August 10, 2001. The sum of each of the 5 model scenarios (with the daily model background values removed from the results of the 4 jurisdictional runs) was compared to the measured 24 hour average ambient $PM_{2.5}$ concentration at that site.

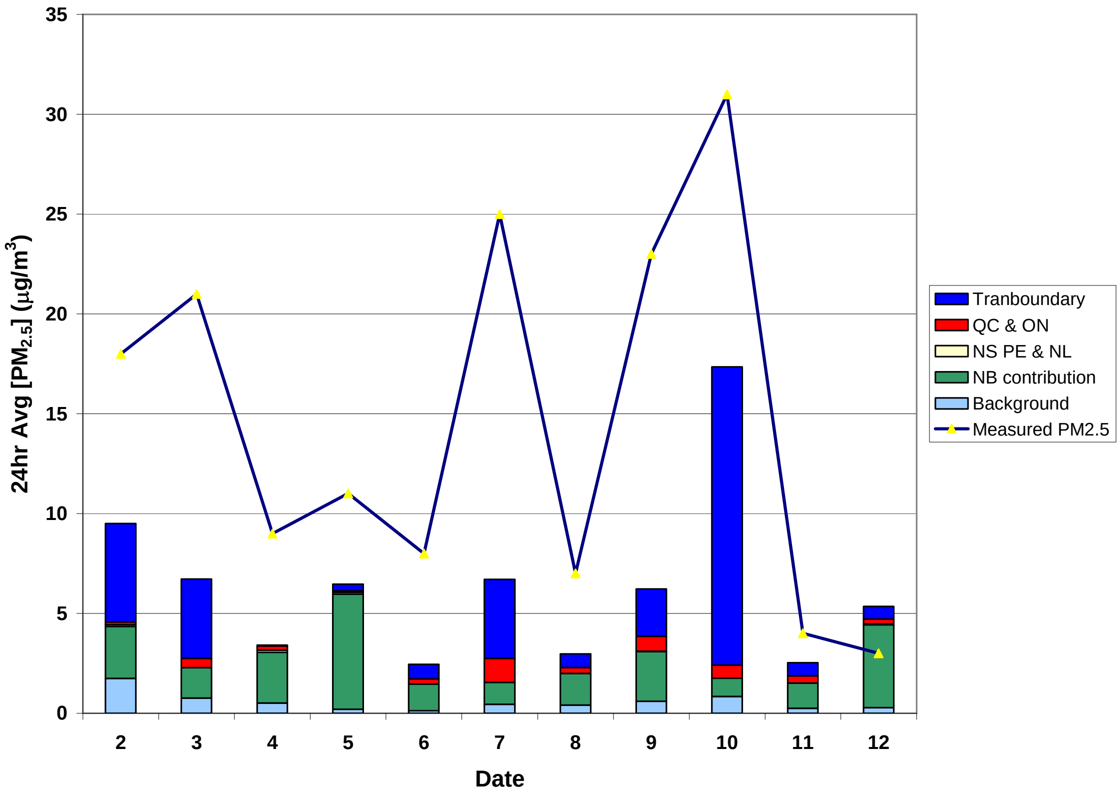

Figure 8. Relative Contributions to CHRONOS Model Fine Particulate Concentration at Saint John – Forest Hills NB 2-12 August 2001

CHRONOS Model fine particulate concentrations do not compare as favourably with measured values as they do for ozone, but it is hoped that the relative contributions from each of the jurisdictions will serve to demonstrate source apportionment.

Figure 9 shows the relative contributions of each of the 4 jurisdictional groupings and natural background to the $PM_{2.5}$ concentration at the Saint John - Forest Hills site as a percentage of the total of the 5 model scenarios.

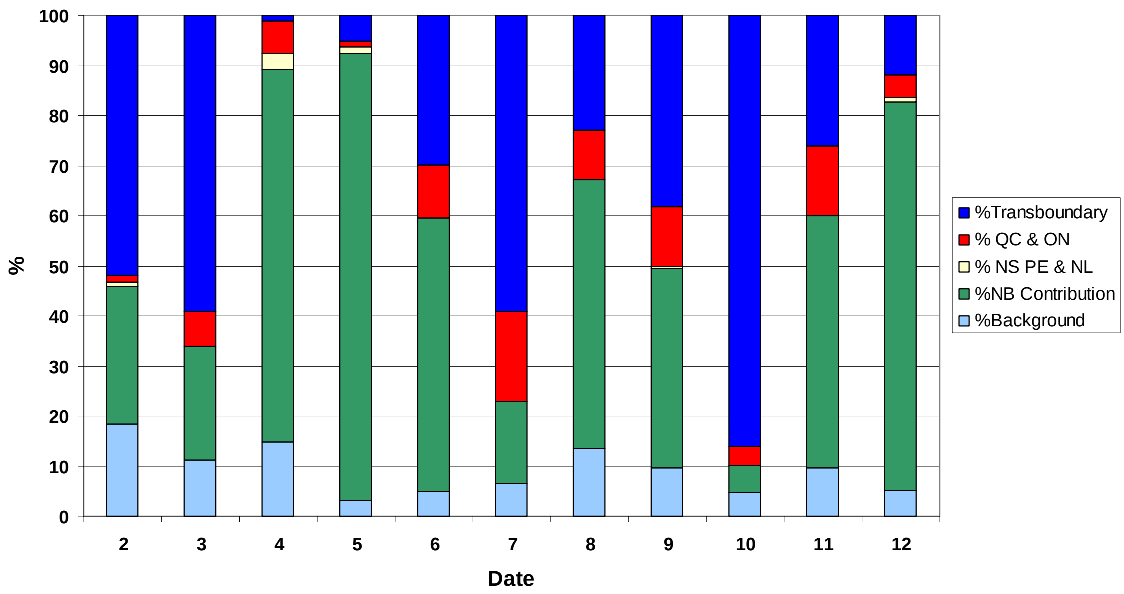

Figure 9. Percent Contribution to CHRONOS Model Fine Particulate at Saint John – Forest Hills NB 2-12 August 2001

The percent contribution by New Brunswick emission sources to $PM_{2.5}$ at the Saint John – Forest Hills site was found to be 5% on August 10, and ranged from 16 to 89% on the other days during the modeled period (Figure 9). Table 6 summarizes the average percent contribution from the various jurisdictional groupings to the CHRONOS model fine particulate concentration, as determined by the 5 scenario runs, on August 10, the day the CWS for $PM_{2.5}$ was exceeded at the Saint John – Forest Hills site.

Table 6. Percent Contribution of Anthropogenic Emissions to CHRONOS Model Fine Particulate Concentration at Saint John – Forest Hills 10 August 2001 (24hr average [$PM_{2.5}$] >30 μgm^{-3})

	% Contribution to CHRONOS 24hr Avg [$PM_{2.5}$]				
Station	**Background**	**NB**	**NS PE&NL**	**QC&ON**	**USA**
Saint John – Forest Hills	*5*	*5*	*0*	*4*	*86*

Table 7. Exceedance of the Canada-Wide Standard for $PM_{2.5}$ at New Brunswick Monitoring Sites: Measured 24 Hour Average $PM_{2.5}$ Concentration and Percent Reduction Expected by CHRONOS Model with No New Brunswick Anthropogenic Emissions

Station	Date	24hrAvg [$PM_{2.5}$]	% NB	Resultant [$PM_{2.5}$]
Saint John–Forest Hills	10 Aug	*31* μgm^{-3}	*5*	*29* μgm^{-3}

The percent New Brunswick contribution to the model fine particulate concentration on August 10, was applied as a reduction to the measured 24 hour average; the resultant value of $PM_{2.5}$ under zero local emissions (i.e. No New Brunswick) is shown in Table 7. The CWS for $PM_{2.5}$ would be met in this case, if only marginally.

CONCLUSIONS

Air quality in the Atlantic Region is highly dependent on meteorological patterns. Trans-boundary transport of air pollutants has the predominant influence on air quality in the Atlantic Region especially during the summer months. The contribution of anthropogenic emissions from different jurisdictions to ambient concentrations of air pollutants varies greatly day to day. Since there is only one day of exceedance of the CWS for $PM_{2.5}$ at one monitoring site during the modeled period, it is difficult to make quantitative statements on the value of emission reductions at the provincial level to local air quality with respect to PM given current CTMs. While there were more instances of exceedance of the CWS for Ozone, the variability of those contributions day to day makes it difficult to determine the amount of reduction to jurisdictional emissions necessary to meet the CWS in all instances. While local emission reductions alone could not be expected to meet the CWS for Ozone at New Brunswick CMAs, they could be expected to have an impact on keeping rural areas downwind of urban areas cleaner.

RECOMMENDATIONS FOR FUTURE WORK

To better quantify the amount of anthropogenic emission reductions required to achieve CWS for $PM_{2.5}$ and Ozone in the Atlantic Region, more episodes of elevated $PM_{2.5}$ and ozone, as well as other CTM model output, should be analyzed. Improvements to CHRONOS modules including the Biogenic Emissions Inventory System and land-use inventories should be implemented in an attempt to have predicted concentrations compare better with measured values. Best efforts to reduce and control the contribution to excess local pollutant levels from anthropogenic sources within a jurisdiction should be tested by re-running CTMs on exceedance cases in the Atlantic Region with planned emission reductions for 2010 for sources within a specific sector and with additional reduction measures as required to satisfy the best efforts criterion.

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APPENDIX A

Relative Contributions to CHRONOS Model Ground Level Ozone – August 2001

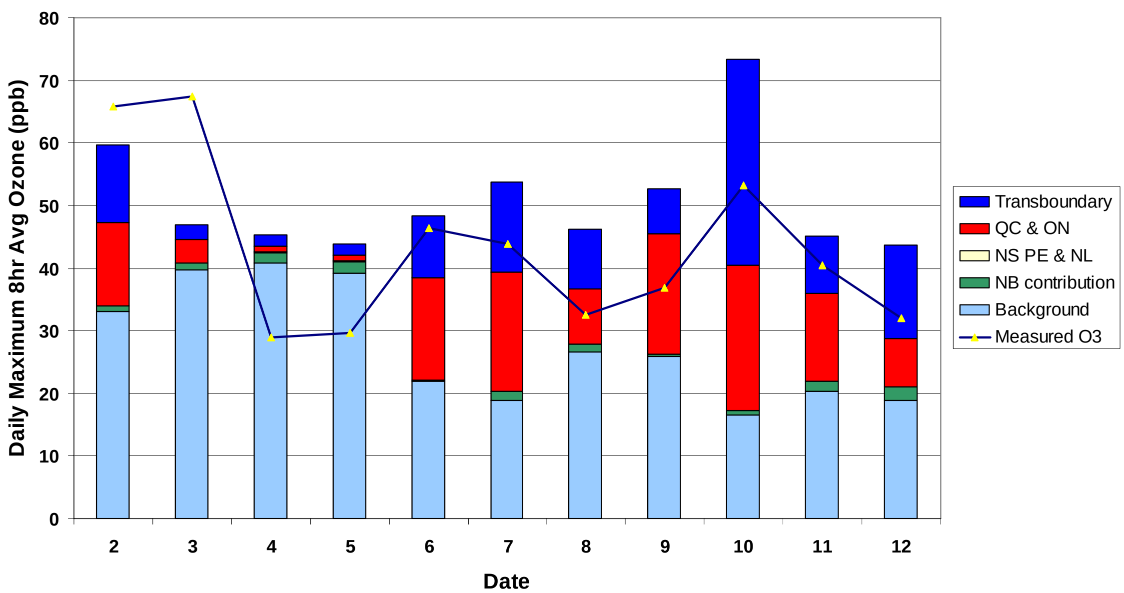

Figure A-1. Relative Contributions to CHRONOS Model Ground Level Ozone at St. Leonard NB 2-12 August 2001

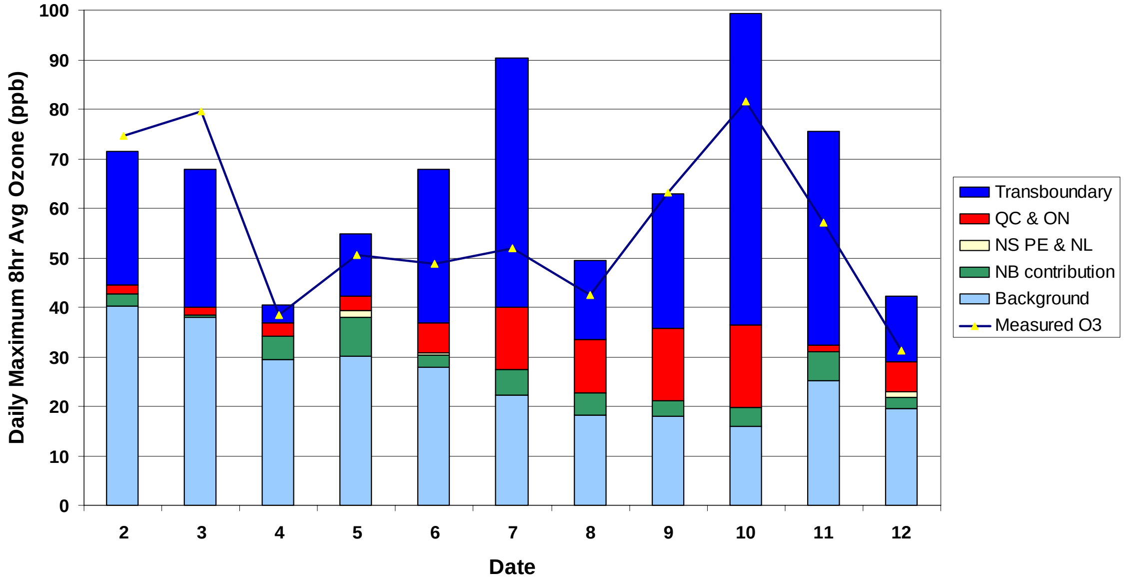

Figure A-2. Relative Contributions to CHRONOS Model Ground Level Ozone at West Side - Saint John NB 2-12 August 2001

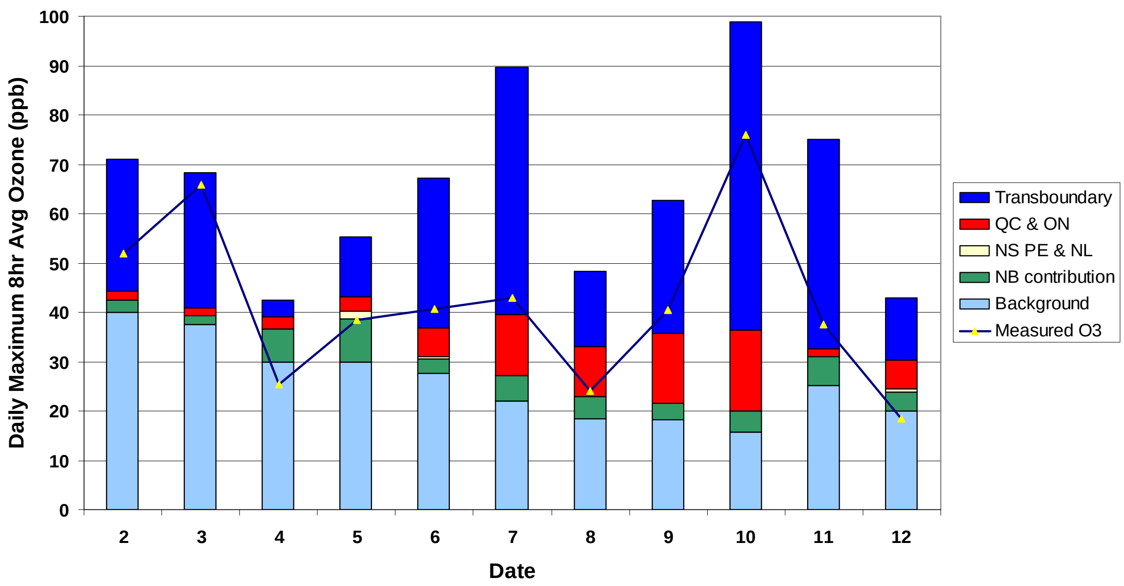

Figure A-3. Relative Contributions to CHRONOS Model Ground Level Ozone at Customs Building – Saint John NB 2-12 August 2001

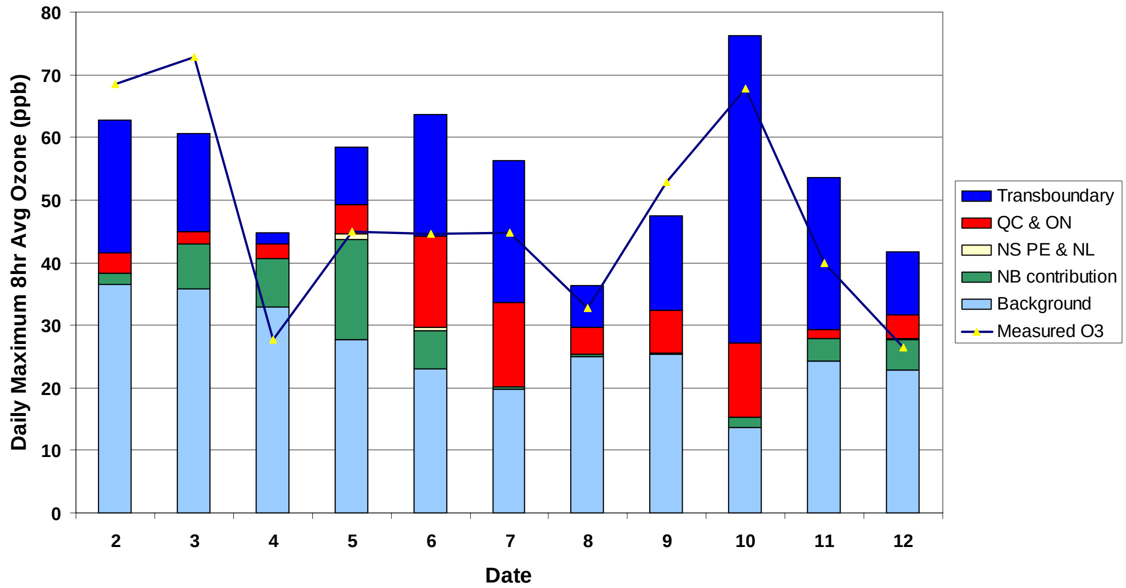

Figure A-4. Relative Contributions to CHRONOS Model Ground Level Ozone at Blissville NB 2-12 August 2001

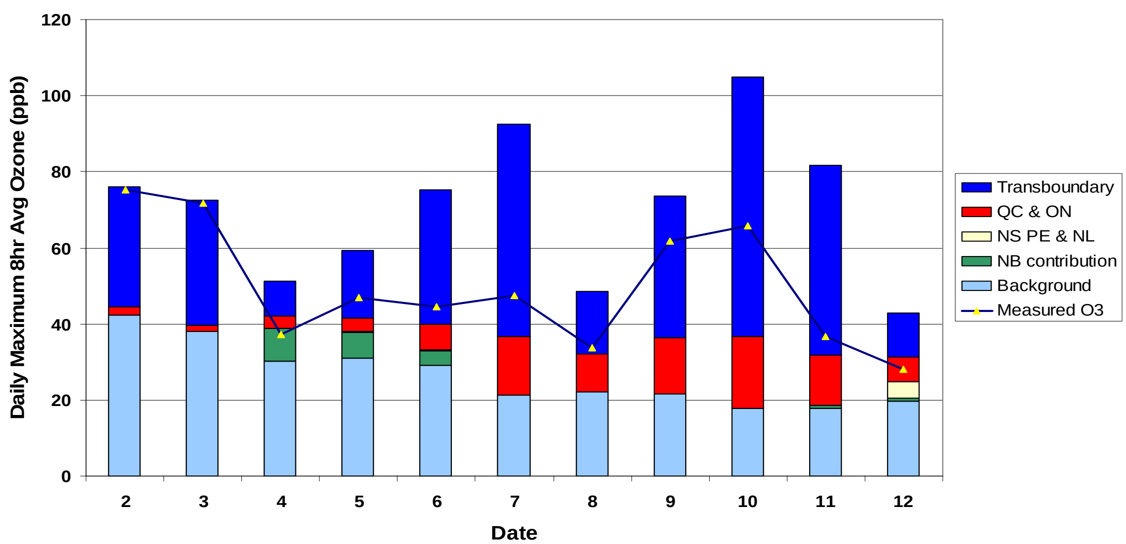

Figure A-5. Relative Contributions to CHRONOS Model Ground Level Ozone at Campobello Island NB 2-12 August 2001

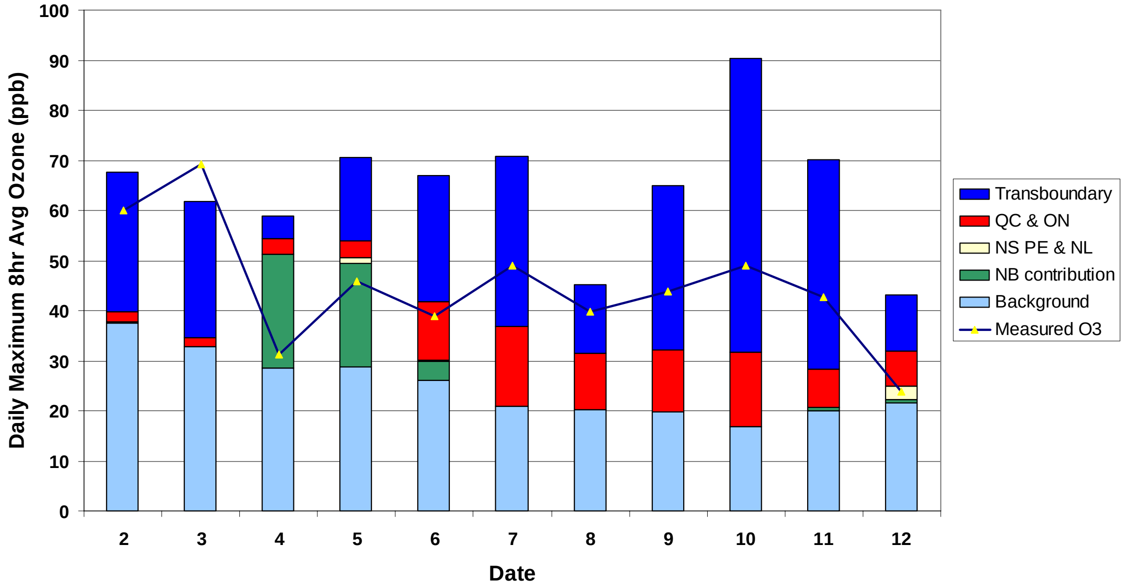

Figure A-6. Relative Contributions to CHRONOS Model Ground Level Ozone at St. Andrews NB 2-12 August 2001

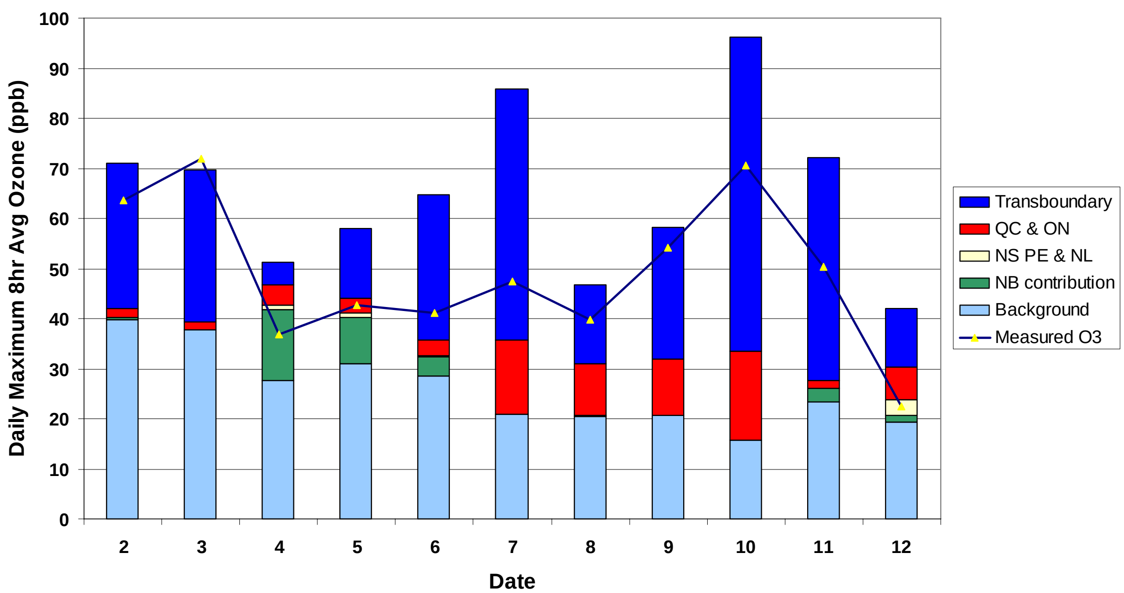

Figure A-7. Relative Contributions to CHRONOS Model Ground Level Ozone at Pt. Lepreau NB 2-12 August 2001

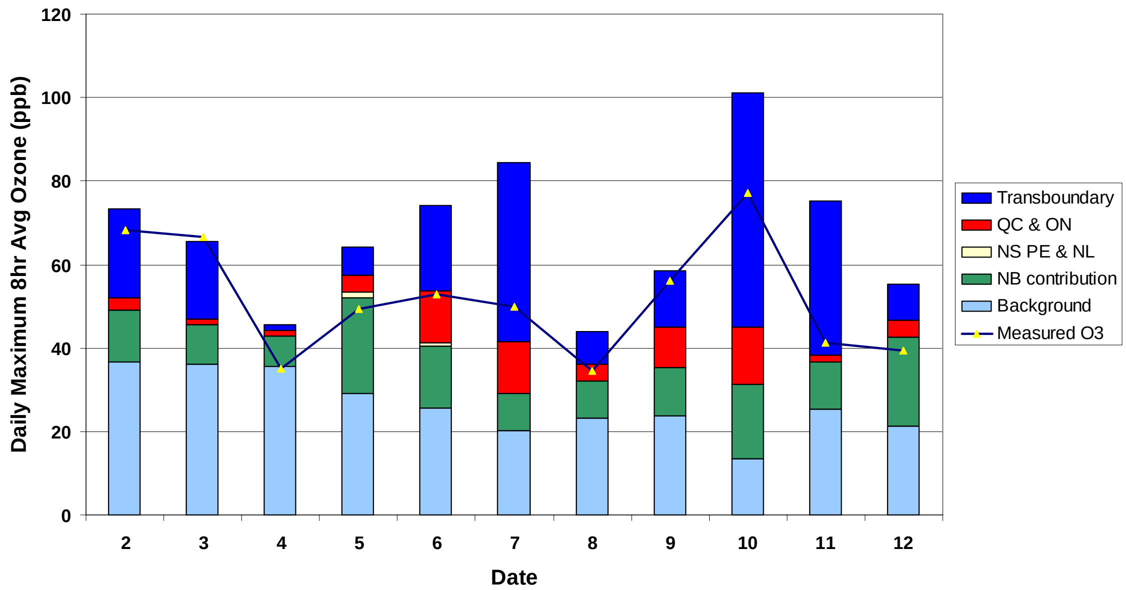

Figure A-8. Relative Contributions to CHRONOS Model Ground Level Ozone at Norton NB 2-12 August 2001

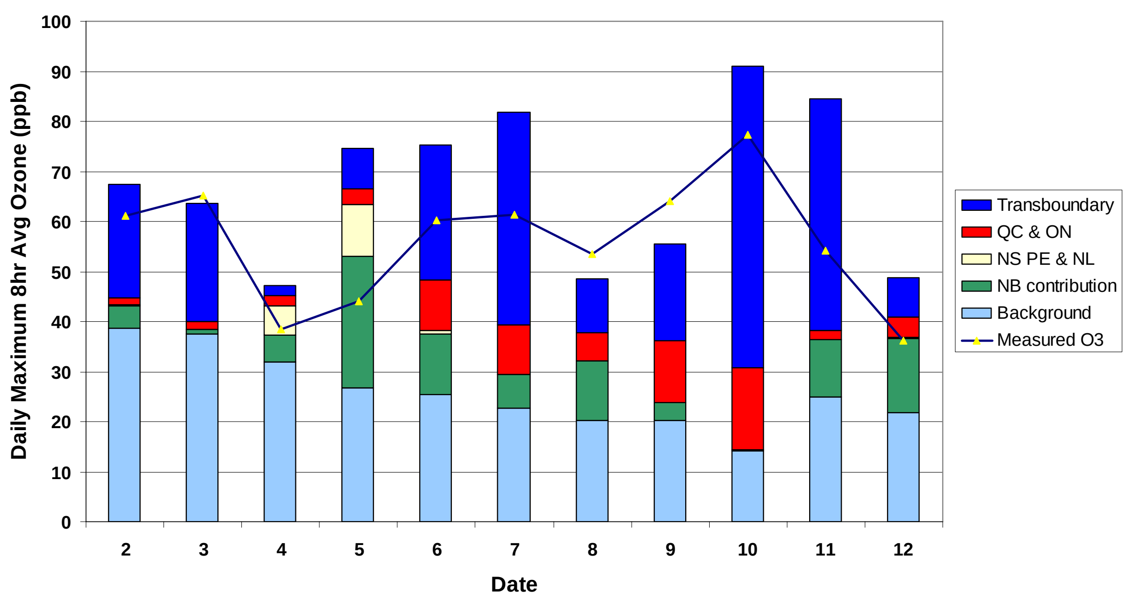

Figure A-9. Relative Contributions to CHRONOS Model Ground Level Ozone at Fundy National Park NB 2-12 August 2001

APPENDIX B

Percent Contributions to CHRONOS Model Ground Level Ozone – August 2001

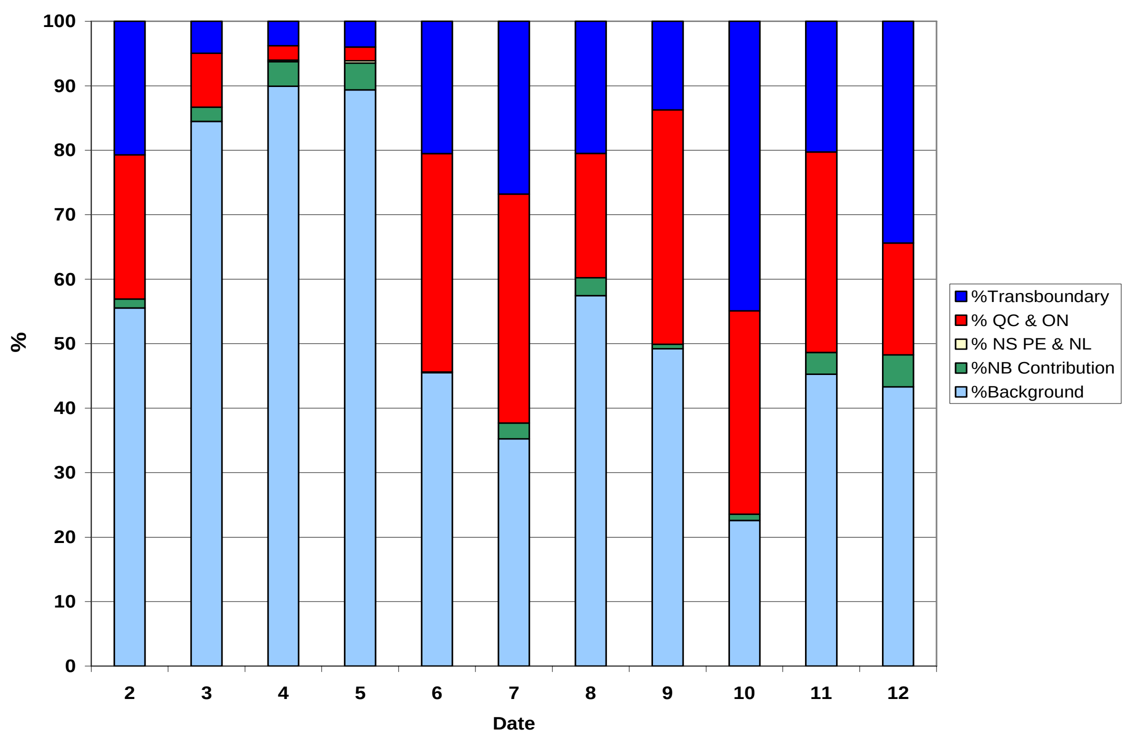

Figure B-1. Percent Contribution to CHRONOS Model Ground Level Ozone at St. Leonard NB 2-12 August 2001

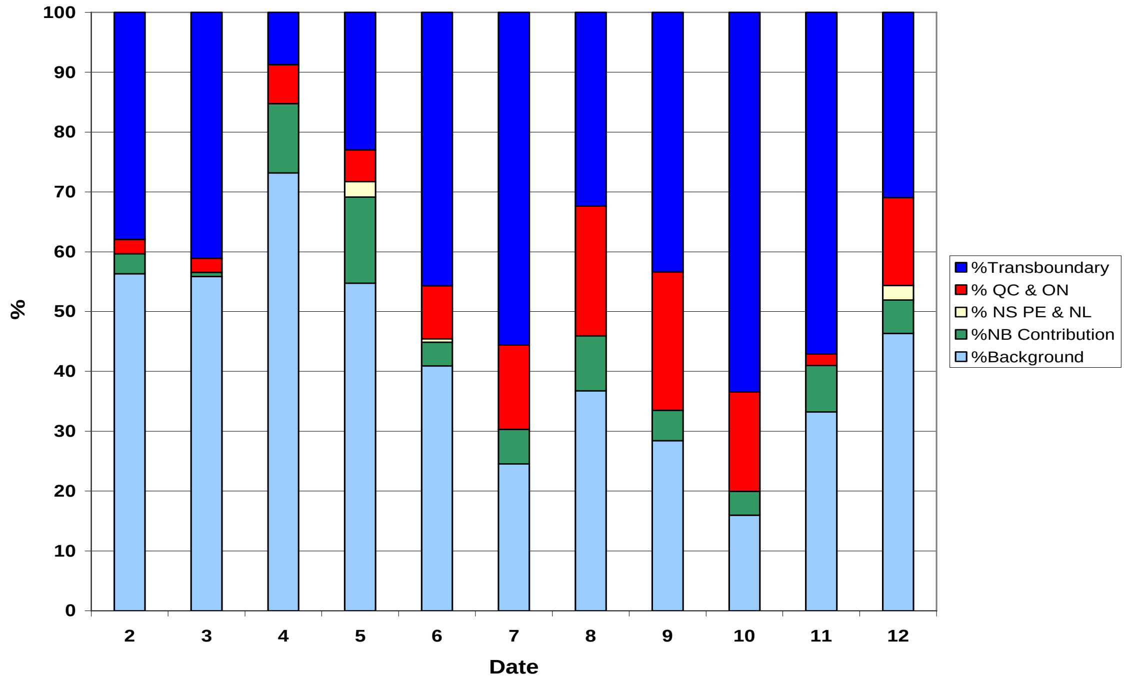

Figure B-2. Percent Contribution to CHRONOS Model Ground Level Ozone at West Side - Saint John NB 2-12 August 2001

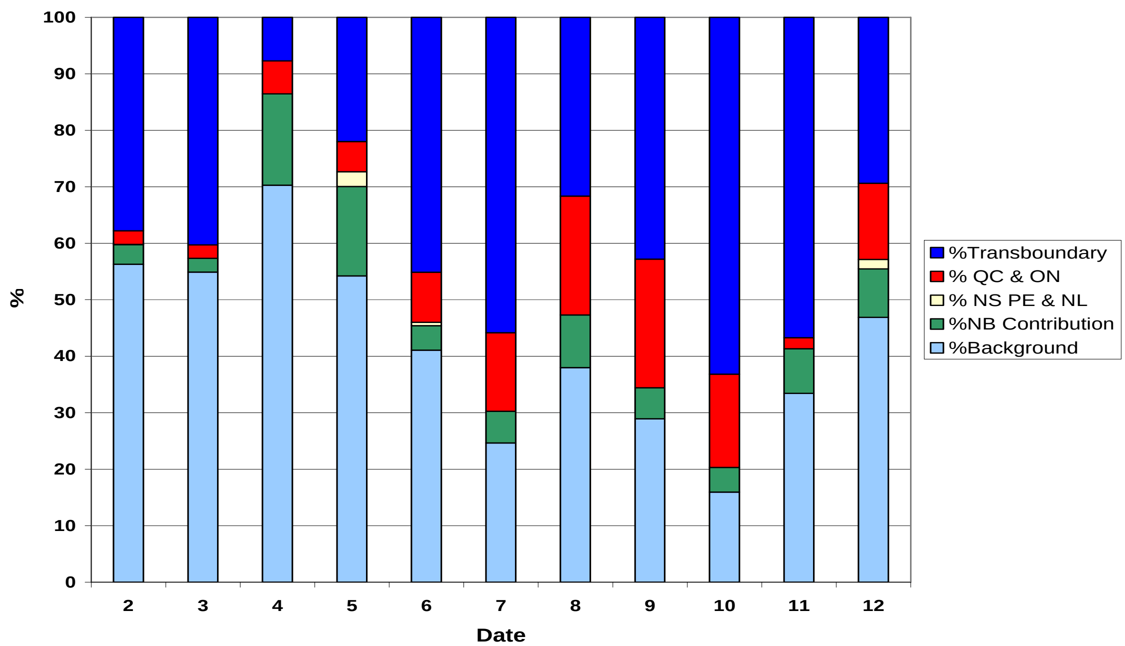

Figure B-3. Percent Contribution to CHRONOS Model Ground Level Ozone at Customs Building - Saint John NB 2-12 August 2001

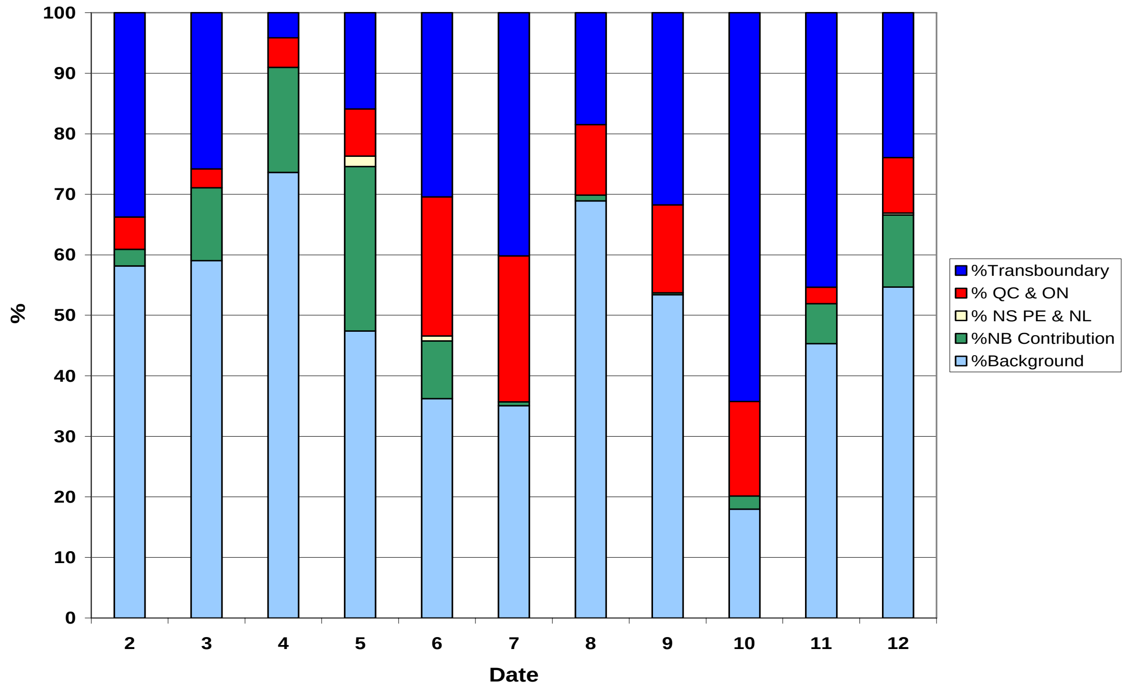

Figure B-4. Percent Contribution to CHRONOS Model Ground Level Ozone at Blissville NB 2-12 August 2001

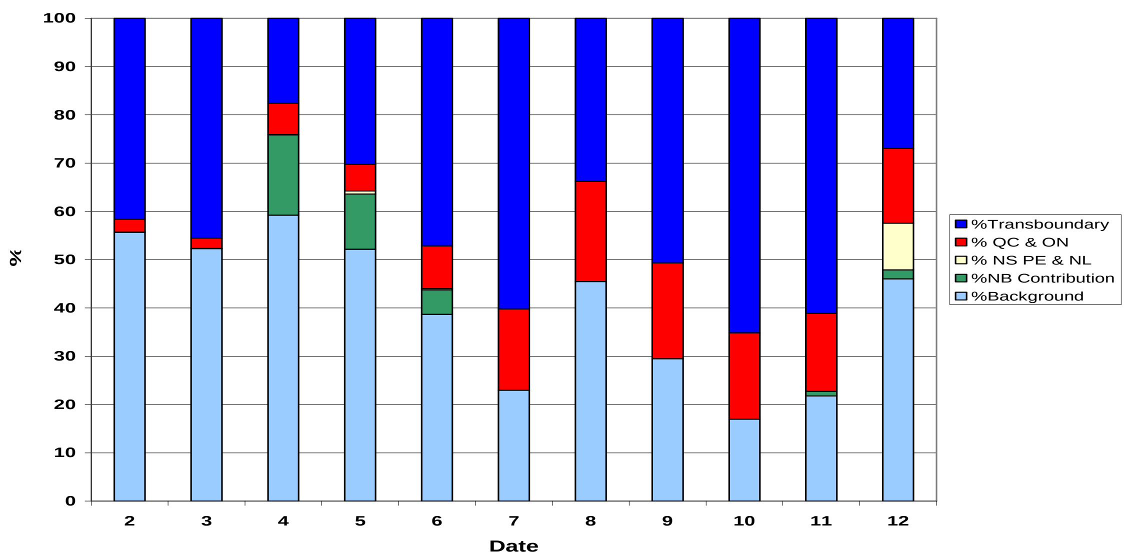

Figure B-5. Percent Contribution to CHRONOS Model Ground Level Ozone at Campobello Island NB 2-12 August 2001

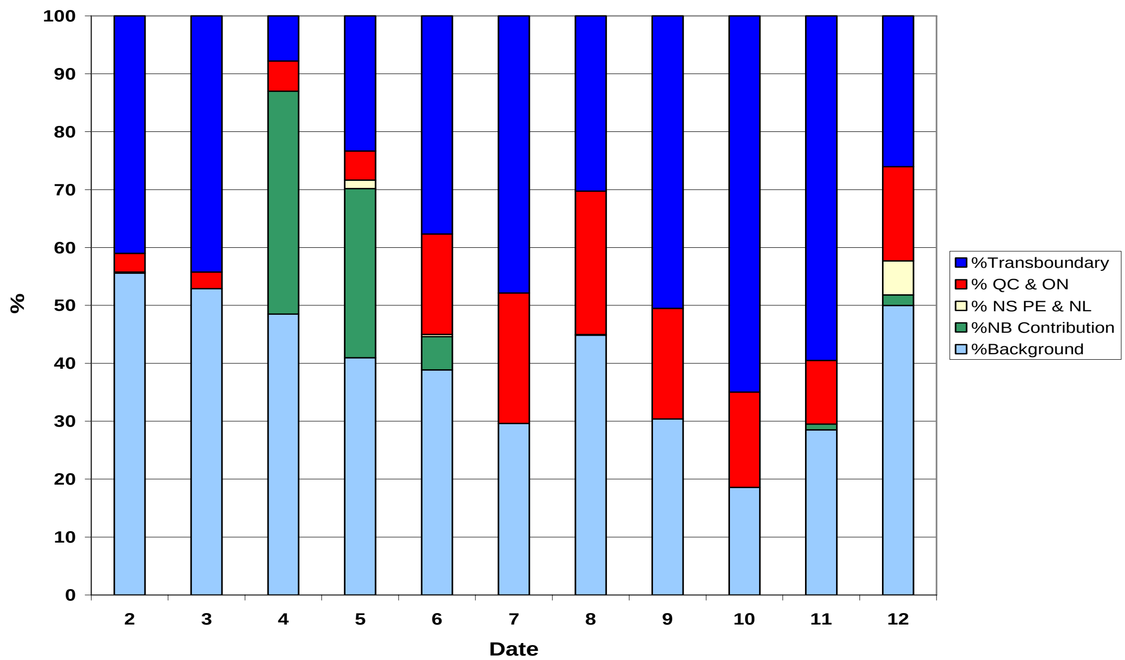

Figure B-6. Percent Contribution to CHRONOS Model Ground Level Ozone at St. Andrews NB 2-12 August 2001

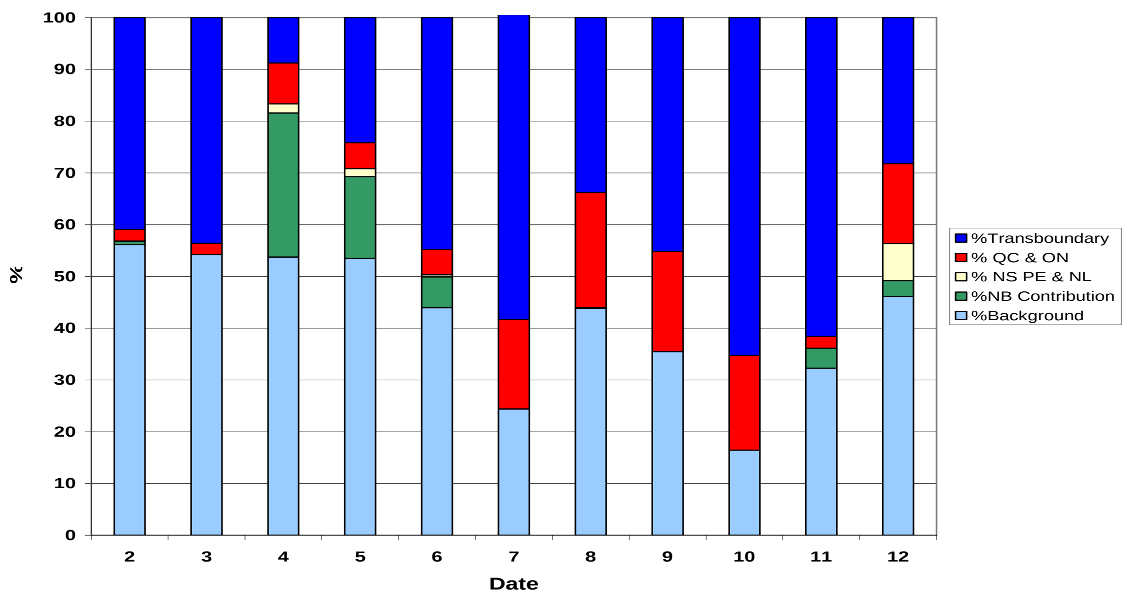

Figure B-7. Percent Contribution to CHRONOS Model Ground Level Ozone at Pt. Lepreau NB 2-12 August 2001

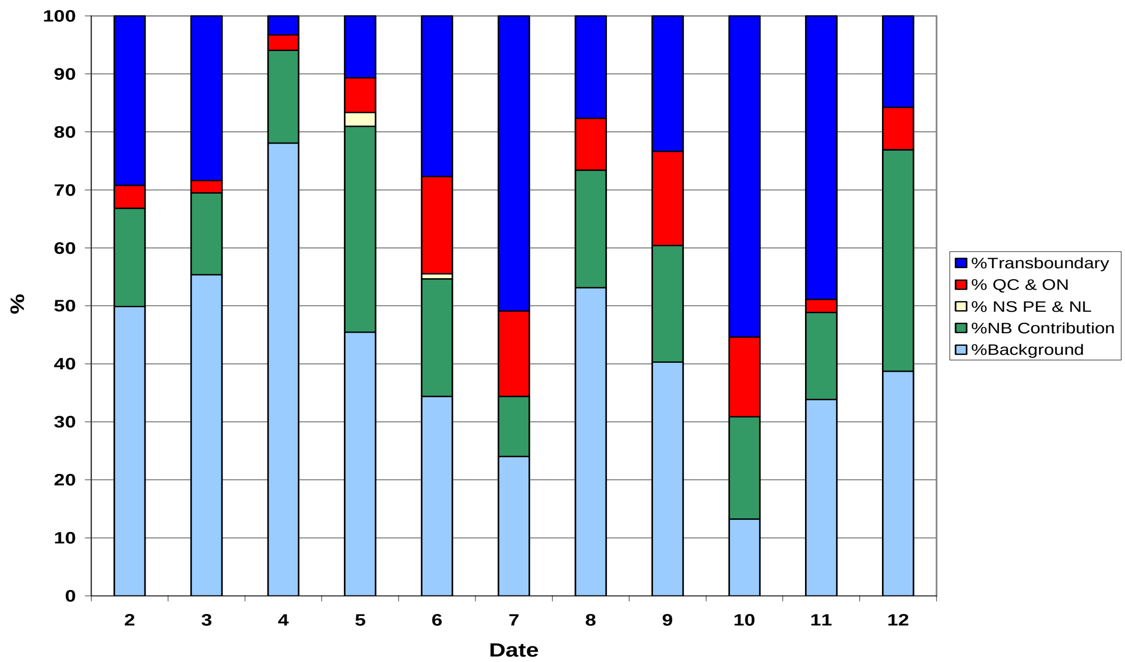

Figure B-8. Percent Contribution to CHRONOS Model Ground Level Ozone at Norton NB 2-12 August 2001

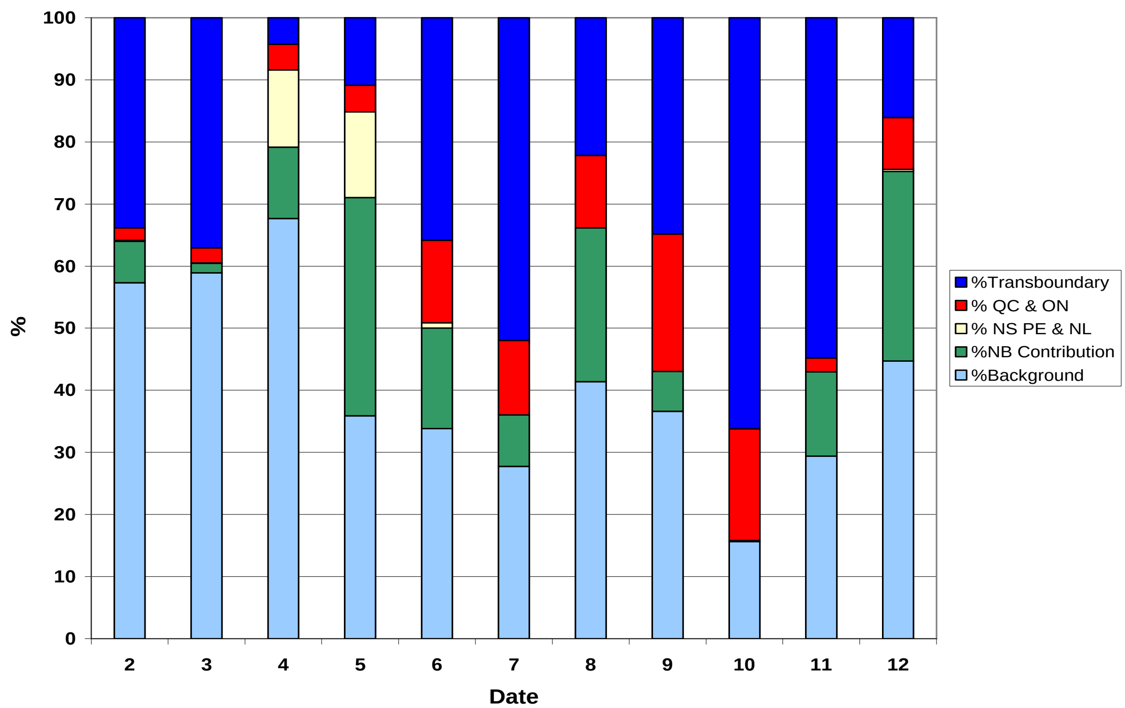

Figure B-9. Percent Contribution to CHRONOS Model Ground Level Ozone at Fundy National Park NB 2-12 August 2001

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