2.6 OPERATIONAL AIR QUALITY FORECASTING IN ATLANTIC CANADA: AN OVERVIEW

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1. INTRODUCTION

Medical research indicates that air pollution has an impact on the health of all Canadians, especially children, the elderly and those suffering from respiratory and cardiac conditions. According to the Canadian Lung Association, during the 1989 to 1992 time frame, respiratory illnesses such as asthma, allergies and other chronic illnesses have increased by as much as 60%. In addition, one in five Canadians suffer from some form of respiratory problem, and lung disease is now the third leading cause of death in Canada.

Federal studies also indicate that there are 5,000 premature deaths a year that can be attributed to air pollution, and the Ontario Medical Association estimates that air pollution costs citizens more than $1 billion per year in hospital admissions, emergency room visits and absenteeism. Furthermore, recent health research has shown that there is no threshold value below which prolonged exposure to smog would not have a negative impact on human health. It is likely that the majority of health effects caused by air pollution occur at ozone concentrations below the value used to issue smog advisories. As such, Atlantic Canadians require information about air quality that is up-to-date and of sufficient frequency. This will allow sensitive individuals with respiratory illnesses, to make their plans based on what they know about their own physical response to air pollution. Daily air quality forecasts, combined with public awareness programs at the community level, allow individuals to make more informed choices.

This paper will highlight the Meteorological Service of Canada's (MSC) Air Quality Prediction Program in Atlantic Canada, focusing on the application of meteorology, the preparation of ground-level ozone forecasts, delivery of these forecasts, and their subsequent value to Atlantic Canadians. In addition, future plans, including the development of a winter dispersion program, will be discussed.

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2. PROGRAM BACKGROUND

The Southern Atlantic Region was identified by studies in the 1970's as an area susceptible to elevated smog concentrations. This led to the implementation of MSC's Smog Advisory Program in New Brunswick in 1993, with the purpose to advise the general public when hourly ozone concentrations were likely to exceed 80 ppbv (parts per billion by volume). This level is currently defined as the National Ambient Air Quality Objectives maximum acceptable limit. Recent installation of state-of-the-art monitoring equipment in other areas of the Atlantic Region has shown that no area is immune from elevated concentrations of ground-level ozone, especially during the summer period (May – October). As a result, the Smog Advisory Program was expanded in 2000 to include all regions of New Brunswick, Prince Edward Island and Nova Scotia.

2.1 *Building on Partnerships and the Smog Advisory Program*

Extensive cooperation amongst various stakeholders has and continues to be an integral part of the program. Principal partners include MSC-Atlantic as well as health and environment departments representing the four provincial jurisdictions in Atlantic Canada including the New Brunswick Environment & Local Government, New Brunswick Health & Wellness, Nova Scotia Environment & Labour, Nova Scotia Health, Prince Edward Island Fisheries, Aquaculture & Environment, Prince Edward Island Health & Social Services and Newfoundland Environment. A further partnership has been fostered with the United States Department of Environmental Protection (US DEP) that has facilitated the International exchange of data and information through its AIRNOW program. This International cooperation has developed as a result of the need for increased co-operation between various jurisdictions. This is due to the recognition of the significance of the long-range transport (LRT) of pollutants, rationalization of fiscal resources, and the availability of new technologies that enable the efficient delivery of timely and accurate information to the general public.

2.2 Upwind Emissions Affecting the Air Quality in Atlantic Canada

The LRT of air pollutants is the single largest component that contributes to poor air quality in Atlantic Canada (Fig. 1).

Figure 1. Geographical location of Atlantic Canada

Air pollution can be transported downwind by as much as 800 kilometers in a single day and its precursors can remain aloft for a longer period and travel much farther. Even though local emissions and production may be modest, the advection of smog from distant locations can result in poor air quality in many communities in Atlantic Canada.

3. SMOG FORECAST PROGRAM IN ATLANTIC CANADA

3.1 Program Delivery

Since July 1997, residents of Southern New Brunswick have had access to a broad range of air quality products including near real-time values of air quality (IQUA), daily forecasts of smog concentrations covering a 48-hour period and additional educational information to improve their understanding of the air quality issue. The program has since been expanded to include all regions within the provinces of New Brunswick, Nova Scotia and Prince Edward Island. Currently MSC-Atlantic and the government of Newfoundland & Labrador are conducting an internal program for eastern Newfoundland with full public program implementation planned for the spring of 2002.

3.2 Dissemination Systems

Several technologies are used to maximize the overall dissemination of air quality information. The use of each of these technologies provides the user with free access to various products. The regional air quality Internet page, http://www.atl.ec.gc.ca/weather/ozone.html, was developed by MSC-Atlantic (Fig. 2). Feedback from the various users on this initiative has been positive, as this newer type of technology has allowed for both easy and efficient access to the latest air quality information.

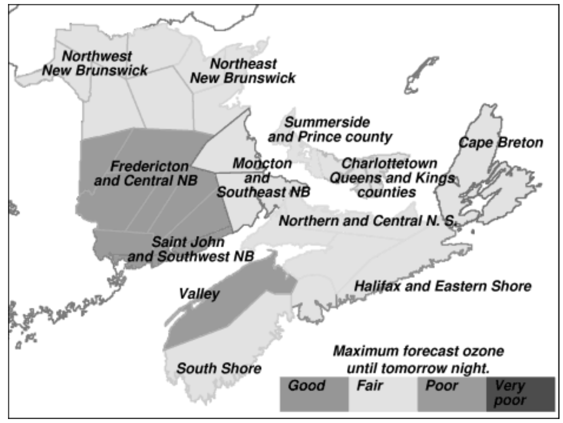

Figure 2. Regional Smog Forecast Website

The smog forecasts, as well as the IQUA bulletin, are available and updated several times per day, in both official languages, on the MSC-Atlantic automatic telephone answering devices (ATADS). The convenience and flexibility afforded to the client, by this mode of delivery, has been proven quite popular.

The smog forecast and IQUA index are also widely distributed by all media. Radio and television have proven to be the most popular means of delivery to the general population, due to its mass dissemination potential.

The introduction of the AIRNOW ozone mapping system (Fig. 3), in May 2001, has also proven beneficial to the promotion and general understanding of the air quality program in Atlantic Canada.

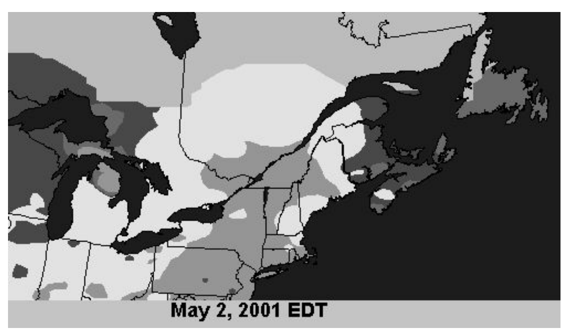

Figure 3. AIRNOW Ozone Map

4. THE AIR QUALITY INDEX (IQUA)

The IQUA (Fig. 4) was originally developed by a subcommittee of the Federal-Provincial Advisory Committee of Air Quality in the late 1970's. The objective of the IQUA system is to provide public information on the adverse effects of the five common air pollutants, sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), ground level ozone (O_3) and coefficient of haze (COH). The philosophy of the index is to produce a simple, useful index that does not underestimate the complexity of the subject. The index identifies the worst effect that may be caused by the mixture of pollutants being measured and is designed to describe the prevailing air quality. The IQUA is categorized according to the National Objectives of desirable, acceptable and tolerable concentrations of each pollutant. For increased understanding, these standards have been respectively translated into the categories of Good, Fair, Poor and Very Poor air quality.

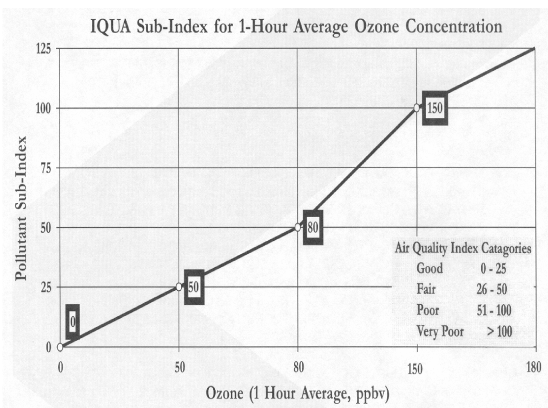

Figure 4. IQUA Sub-Index and categories related to ground-level ozone

Due to public familiarity with the IQUA system, it was decided to use the IQUA Sub-Index related to ozone for the smog forecast program. Ozone concentration reports and forecasts are then translated into an air quality index that is more suitable to the general public.

5. FORECAST PRODUCTION

The occurrence of elevated smog concentrations in Atlantic Canada is dependent on several factors, including local production due to photochemical reactions, and local and regional meteorological conditions. The LRT of pollutants is a very significant component of smog concentrations in the region, and has been estimated to contribute as much as 85 percent of the smog total during episodes. Meteorologists require a solid understanding, not only of local meteorological, formation and deposition mechanisms, but also of the past and current weather in the upstream areas. This is crucial to the forecasting process. Pattern recognition, synoptic set-up, leading to high smog concentrations, and an appreciation for the climatology associated with elevated smog concentrations, all contribute to forecast production.

5.1 *Smog Climatology*

Elevated smog concentrations are episodic and most prevalent during the summer months when meteorological factors are most favorable for both smog formation and transportation into the region. This transport component has been studied through back-trajectory analysis and points to the heavily populated Northeastern United States and the Windsor-Montreal corridor as the major source regions. Although the seasonally averaged smog concentrations show smooth diurnal ozone patterns, sites in Atlantic Canada are strongly affected by LRT of ozone and its precursors, with mixing ratios of 100 ppbv or more having occurred. Climatological studies conducted by staff at the Atmospheric Science Division (ASD) of MSC, show the occurrence of elevated smog concentrations during the overnight period when there is no local photochemistry, which indicates the significance of the LRT component. Meteorologists also benefit from the knowledge of a greater likelihood of elevated smog concentrations at the end of the week.

The location of the ozone monitors and local topography also play a significant role in the understanding of smog behavior. Much of the forecast area lies adjacent to large bodies of water. Therefore, local inversions, due to radiation cooling and/or the marine influence, play a significant role in the overall air quality. A contrast is evident in the climatology between the coastal monitoring sites, which are affected by the marine boundary layer and sea breeze regimes, the urban sites, where local scavenging by nitric oxide (NO) is significant, and the rural sites, which have a "typical" diurnal trend of a distinct overnight minimum and an afternoon or early evening maximum.

5.2 *Pattern Recognition*

Upwind emission sources play such an important role in the resulting air quality in Atlantic Canada that the atmospheric conditions over the emission areas must be considered before deciding if there is a potential for elevated smog concentrations in the region. Weather patterns that allow for strong photochemistry and precursor build-up, along with a favorable synoptic pattern that pushes the formed ozone and precursors into the Atlantic region, are signatures of elevated smog concentrations.

5.3 *Synoptic Set-Up*

An appropriate pattern for elevated ozone concentrations involves a high-pressure area with strong ridging in the middle troposphere over the emission regions of the Northeastern United States and Southern Ontario (Fig. 5). This pattern would include:

- Strong photochemistry
- A strong temperature inversion to minimize vertical dispersion
- Strong upper ridge located to the east of the region with 850 MB temperatures ≥ 15 °C
- Maximum surface temperatures ≥ 25 °C
- Light to moderate winds from source regions
- A lack of precipitation to minimize "washout"

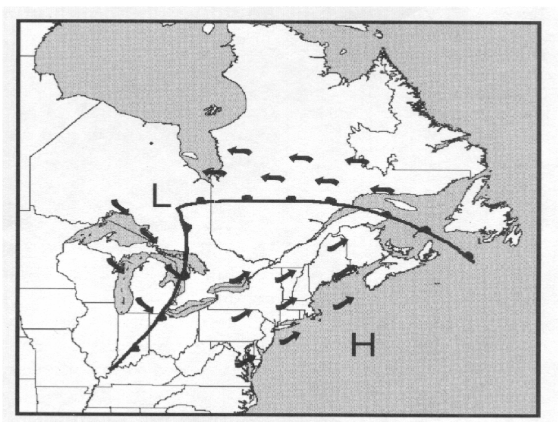

Figure 5. "Typical" synoptic set-up showing positions of pressure systems during periods of elevated O_3 concentrations in Atlantic Canada. Arrows indicate the predominate wind-flow directions.

These conditions must persist for a minimum of two days to allow for sufficient smog formation and build-up. In addition, a low-level jet of ≥ 15 m/s in advance of an approaching frontal trough would support the necessary southwesterly advection of ozone and its precursors into the Atlantic Region air shed. Appropriate weather conditions are required over the receptor area including:

- Atmospheric circulation from source regions
- Insolation to aid local smog production
- Breakdown of the inversion to permit mixing of precursors down to the surface

A westerly circulation from the industrial northeast can result in a buildup of pollutants in the "reservoir" over the Gulf of Maine. The subsequent sea breeze and synoptic southwesterly flows can advect these pollutants onshore at the coastal sites even in foggy conditions. Generally, for inland sites, sunny conditions and temperatures in the mid to upper twenties °C support elevated smog concentrations.

5.4 *Tools and Support*

The following is a listing of the bulletins and computer model output, which are an integral part of the forecasting process:

- Real-time data and air quality bulletins from upstream regions including US DEP bulletins, forecast discussions, real-time data and AIRNOW maps
- Computer guidance
  - Global Environmental Model (GEM)
  - Air Quality package (including mixing layer heights, streamlines, winds at specified levels, wind mileage and ventilation coefficients)
  - **C**lassification and Regression Tree **A**daptive **N**euro **F**uzzy **I**nference **S**ystem (CANFIS)
  - **C**anadian **H**emispheric **R**egional **O**zone and **NO**$_X$ **S**ystem (CHRONOS)
- **W**eather **A**nalysis and **D**isplay **S**ystem (WADS) for prognosis of inversions and velocity fields, etc.
- Back-trajectories for sites in the Atlantic Region
- Other numerical guidance

The operational models currently used are the Semi-Lagrangian Atmospheric Chemistry Model, CHRONOS (Fig. 6), developed by Pudykiewick et al., and the CANFIS developed by Burrows and Monpetit.

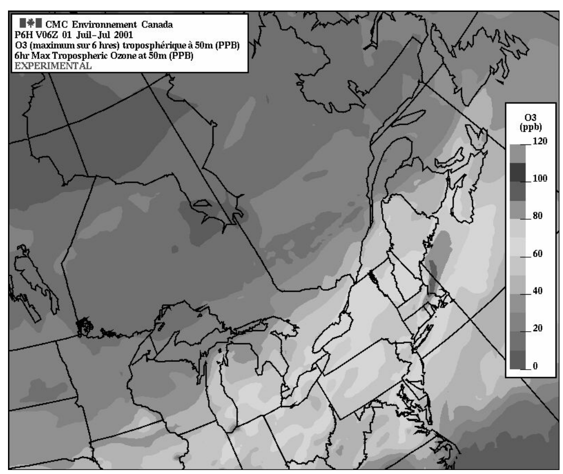

Figure 6. CHRONOS output at 50 metres: Valid 0600Z, July 1, 2001

The CHRONOS integrates the meteorological component of Environment Canada's Global Environmental Multiscale (GEM) with the chemistry component of the Acid Deposition and Oxidants Model (ADOM-2). The present resolution is 24 km with forecast output to 48 hours at 10, 50 and 500 metres. The CANFIS is a non-Linear regression procedure to produce statistical air-quality forecasts.

5.5 *Procedures*

The meteorologist initiates an assessment of the various factors that affect smog concentrations by integrating meteorological and air quality information within a conceptual understanding of smog behavior. Following the evaluation of current conditions and identifying the various factors responsible, a daily forecast of smog is produced for regions of Atlantic Canada. In addition, when smog concentrations are expected to exceed 80 ppbv, a smog and health advisory bulletin is issued.

6. SMOG FORECAST CONTENT AND DISSEMINATION

The daily smog forecast is issued twice daily at 5:00 AM and 4:00 PM local time, May through October inclusive. The morning bulletin provides 43-hour information for Day 1 from 5:00 AM through midnight on Day 2. The afternoon issue covers the 32-hour period from 4:00 PM on Day 1 through midnight on Day 2. Revised forecasts are also produced if required.

6.1 *Bulletin Content*

The bulletin consists of a regional smog forecast, FLCN40/41/42/43 CWZF, similar in format to other text bulletins issued by the MSC. The principal objective of this product is to provide information on the expected evolution of smog levels for a period of up to 43-hours. Various tools and scientific knowledge are integrated to produce a single numerical forecast value (sub-IQUA) and a categorical value.

One of the principal objectives of the program is to build an environmental prediction capacity within the MSC to meet the evolving needs of Canadians. Information gained from recent medical studies related to smog exposure, as well as a need for additional public education on air quality, are also taken into account. These objectives are nourished through the inclusion of a health and education message segment.

A suite of education and health messages were designed to inform and increase the public awareness of the air quality issue. This section of the bulletin provides enhanced public information on the health effects related to ozone exposure.

In addition, a graphical representation of the forecast ozone concentrations are available on the MSC-Atlantic website for each of the forecast regions (Fig. 7).

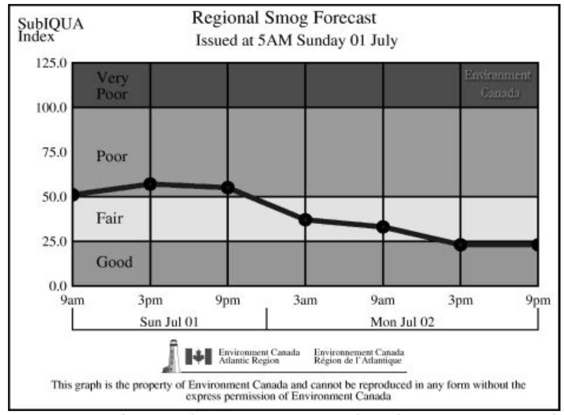

Figure 7. Smog forecast graph for Greenwood, NS valid 5:00 AM, July 1, 2001

Information from MSC-Atlantic is also available by accessing Environment Canada's Clear Air site at http://www.ec.gc.ca/air/introduction_e.cfm.

7. FUTURE PLANS

Continued improvements and expansion to the MSC-Atlantic Air Quality Program are planned for the 2002 –2003 time frame. These include:

- Expansion of the Smog Daily Forecast and Advisory programs to include the province of Newfoundland
- Operational implementation of a higher resolution CHRONOS model (16 km)
- Automation of routine operational bulletin preparation
- A Winter Dispersion Pilot Project to be launched in the cities of Saint John & Fredericton. Available from December through April, the objective of this new program is to forecast the occurrence of atmospheric conditions conducive to the accumulation of pollutants, such as those associated with wood smoke or transportation (vehicles), which can be detrimental to human health. This program, based on work already completed by MSC-Quebec, will include the identification of representative sites, installation and/or relocation of $PM_{2.5}$ and meteorological sensors, forecast model development and staff training
- $PM_{2.5}$ Forecast Pilot Project
- Adoption and program implementation of the new Canada-Wide Standards for PM and Ground-level Ozone
- Development of an ab-initio Air Quality training module for operational MSC meteorologists
- Focused public education & awareness programs engaging community participation

8. A CASE STUDY

As an illustration of the complexity of the forecast problem in Atlantic Canada, and the interaction between the various atmospheric components, the following provides detailed study of a typical synoptic set-up resulting in a significant deterioration of air quality. The event occurred from July 23 through July 25, 2001.

8.1 *Synoptic Conditions*

During the period of July 19th through 25th, a persistent northeast-southwest ridge of high pressure was situated across the Eastern Seaboard of North America. This resulted in a southwesterly circulation of hot and humid tropical air pushing northwards enveloping the east coast with afternoon maximum temperatures in many inland localities reaching the low to mid 30's °C. The only exceptions were coastal communities where daytime highs of near 20 °C were recorded due to a synoptic onshore wind. In addition, late afternoon dew points where generally reported in the 17 to 22 °C range.

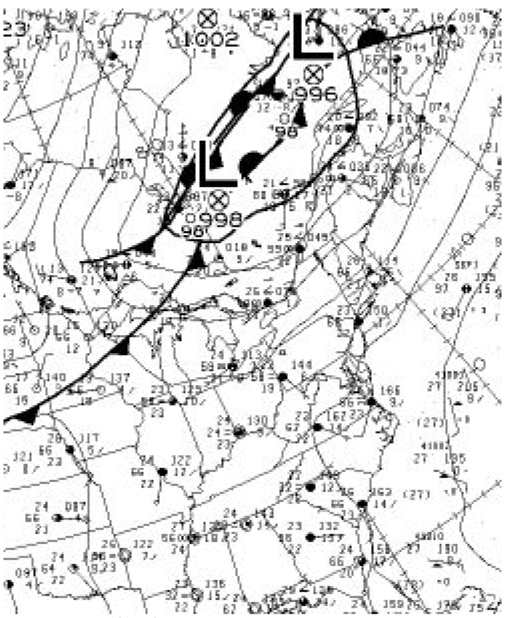

Figure 8. Surface analysis valid at 1200Z, July 24, 2001

These conditions, combined with light surface winds, a strong subsidence inversion, and 850 hPa temperatures in the 17 to 20 °C range, resulted in favourable conditions leading to significant photochemical production of ground-level ozone (GLO) over a vast region of Eastern North America. As a result, a gradual deterioration of air quality was reported across the Maritimes on July 23rd. Also of importance was a cold-frontal trough approaching the Maritimes slowly from the northwest.

As the ridge moved east into the open Atlantic early on July 24th (Fig. 8), a light to moderate southwesterly circulation resulted in minimum boundary layer mixing and subsequent ventilation of the polluted plume throughout the region. GLO readings in the Maritimes, which had generally been in the 30 to 40-ppbv range throughout the day on July 23rd, began to rise across western inland regions of New Brunswick and Nova Scotia during the evening hours. Peak values in the low 70's to mid 80's-ppbv range were reported by late evening, with the Aylesford, Nova Scotia monitor reporting a peak value of 86 ppbv (Fig. 9). Upstream peak ozone readings exceeded 100 ppbv at many sites throughout Southern New England, New York State, Pennsylvania, Southern Ontario and Southern Quebec.

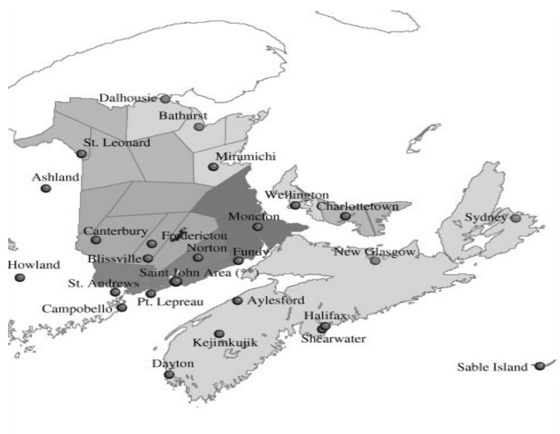

Figure 9. Ground-level ozone monitor network

Back-trajectories for the period of July 23rd through 25th indicate the arrival of the contaminated air parcel across the Maritimes. With very little ozone scavenging occurring over the Gulf of Maine and Atlantic waters, and a strong marine inversion reported, it is assumed that the integrity of the polluted plume was maintained as it crossed Southern Maine before arriving in the Maritimes.
Considering the strong surface temperature inversion, it is estimated that the tongue of contaminated air encompassed by the 1000 to 925 hPa back-trajectories (Fig. 10) was representative of the advected plume axis.

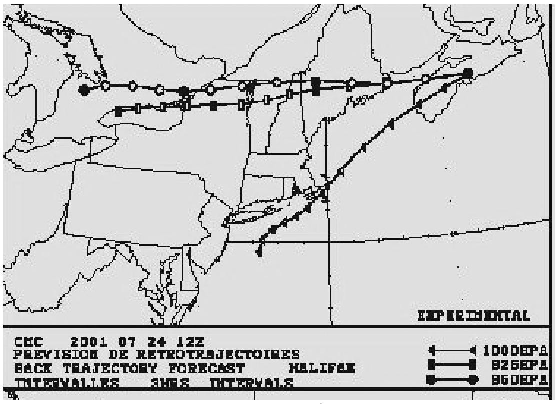

Figure 10. Back-trajectory forecast valid 1200Z, July 24, 2001.

As shown in Figure 11, ground-level ozone values were significantly higher in the Aylesford area primarily as a result of LRT, but also due to photochemical production and topographical considerations. Meanwhile, monitoring sites along coastal New Brunswick and Nova Scotia remained rather uneventful with peak readings ranging from 32 to 49-ppbv. By late evening on July 24th, GLO values at Aylesford had peaked at 88 ppbv. GLO values dropped significantly during the early morning hours of July 25th with the passage of the cold front from the northwest. O_3 values settled back into the 25 to 45-ppbv range at all reporting stations by noon on July 25th as a westerly circulation of cooler but relatively clean air became established across the region. It should be noted that all coastal sites are considered to be within one to two km of the adjacent body of water. Study has shown that the polluted plume overrode the coastal sites that were significantly affected by the marine inversion.

Date	Halifax	Dayton	Aylesford	Saint John
July 23	49	20	86	46
July 24	48	19	88	47
July 25	39	32	74	43
July 26	21	24	30	20

Figure 11. Comparison of coastal versus inland peak O_3 concentrations in ppbv, July 23-26th, 2001

For example, during the event, coastal sites reported surface temperatures near 20 °C while inland readings reached the low to mid 30's. With the development of advection fog in the Gulf of Maine as well as coastal New Brunswick and Nova Scotia, the plume of concentrated ozone aloft was unable to mix downwards at the coastal sites and penetrate the strong marine inversion. However, inland sunshine and the resulting diurnal convection, allowed for mixing of the plume to the surface resulting in significantly higher readings.

9. CONCLUSION

MSC-Atlantic meteorologists have exhibited significant skill in forecasting daily concentrations of ground level ozone since program inception in 1997. As well, accuracy has continued to improve as meteorologists gain experience. This has resulted in the ability of MSC-Atlantic to provide Atlantic Canadians with up-to-date and factual air quality information such that they are able to take an informed decision to protect themselves, their families and the environment.

It is anticipated that increased familiarity and experience with local and regional behaviour of GLO and $PM_{2.5}$, improved numerical and statistical models resulting from various research initiatives, case studies from past ozone events and enhanced automation of forecast tools, will all contribute to improved forecast accuracy and delivery in the near future.

10. ACKNOWLEDGEMENTS

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