METEOROLOGICAL ANALYSES OF ACIDIC PRECIPITATION IN ONTARIO

D. Yap and J. Kurtz
Air Resources Branch
Ontario Ministry of the Environment
125 Resources Road, Rexdale, Ontario, Canada
M9W 5L1

ABSTRACT. Meteorological analyses of precipitation and air quality data for the period 1976 to 1983 have been undertaken to infer potential source regions of acidity in Ontario. Techniques such as air parcel trajectory modelling and synoptic weather classification have been utilized. A meteorological data acquisition system has been implemented to provide historical and real-time trajectory statistics. This paper provides an overview of these studies. For areas of South and Central Ontario, precipitation events most commonly occur with pre-warm front and cyclonic situations, and trajectories from the south and southwest octants. Furthermore, most of the reported wet deposition of S and N is associated with trajectories from these octants, the direction of the Ohio Valley industrial source region and industrialized SW Ontario. High air concentrations of S and N are also associated with trajectories from these octants.

1. INTRODUCTION

As part of the Acidic Precipitation in Ontario Study (APIOS) program, a meteorological data acquisition system (MDAS), capable of providing support for special studies, as well as modelling activities, has been designed, developed and implemented. This computerized system is a package designed to receive weather teletype information from Canada's Atmospheric Environment Service (AES) and to store the incoming data in a form suitable for retrieval and further processing.

The area covered by MDAS extends approximately east of the Rockies and north of Florida. Air parcel trajectories, terminating or originating at a specific location, can be

Water, Air, and Soil Pollution **30** (1986) 873–878.

calculated by the system for interpreting precipitation events and air quality data. To date, trajectory analyses have been provided for events at various locations in Ontario and Eastern North America. MDAS is a multi-role system that assists the Air Resources Branch of the Ontario Ministry of the Environment in the performance of numerous functions, including long-term, episodic and real-time studies of acidic precipitation in Ontario. The package is currently implemented on a Data General Eclipse series mini computer. The major capabilities of the MDAS system consist of data acquisition, tabular output, graphics output, analysis programs, trajectories, archiving, macros and on-line documentation. A sample of the output produced by MDAS for acidic precipitation studies is shown in Figure 1.

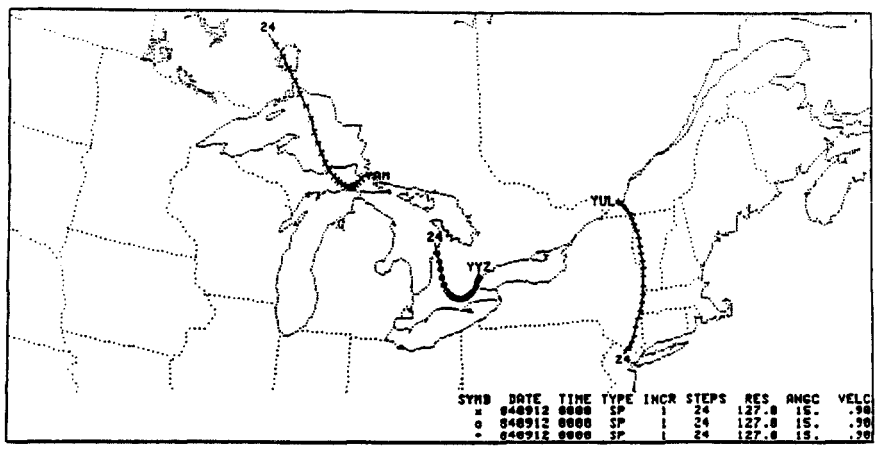

Figure 1: Three 24h forward surface trajectories calculated at one hour time steps.

In this paper, a summary of the meteorological studies for the period 1976 to 1983 is presented.

2. PRECIPITATION AND AIR QUALITY DATA

Air quality and precipitation chemistry concentration data for these studies were primarily obtained from the Acidic Precipitation in Ontario Study (APIOS) network for the period 1980 to 1983. Some earlier data (1976-1979) were collected for the Muskoka-Haliburton Region of Ontario as part of the Lakeshore Capacity Study. The province-wide APIOS networks (cumulative and event), operated by the Ontario Ministry of the Environment, were established in 1980 and 1981 to monitor both wet and dry deposition respectively (for details, see Chan et al., 1982). The event

network stations, suitable for meteorological data analysis, are located in four clusters, but only one station for each cluster was used in this study, namely, Longwoods, Railton, Dorset and Fernberg (Figure 2).

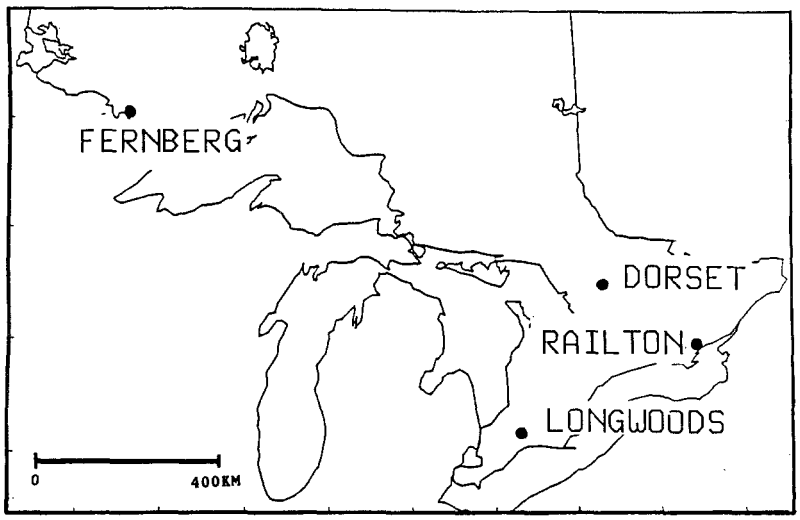

Figure 2: Location of the event network monitoring stations. Dorset is situated in the Muskoka-Haliburton Area of Ontario.

3. AIR PARCEL TRAJECTORY AND SYNOPTIC WEATHER SCHEMES

3.1. The Trajectory Model and Analysis Technique

Neglecting acceleration, representative horizontal winds (u and v components) in the atmospheric boundary layer are obtained from the surface and 850 mb geostrophic winds, with modifications for surface frictional effects. The task is accomplished with an objective analysis scheme using synoptic weather data from approximately 300 stations in a 30 x 30 grid system (grid length 127 km) for the surface level and using the height fields on a 11 x 11 grid system (grid length 381 km) for the 850 mb level. To obtain air parcel trajectories terminating or originating at a specific location, the three-hourly (typically) wind vector (surface) and the twelve-hourly wind vectors (850 mb) are integrated with backward or forward time-steps over the required periods, up to 2 to 3 days. Trajectories beyond this time period are not recommended since air flows then are likely to be subjected to significant curvature.

In these studies the possible source regions for wet deposition are inferred from the 850 mb (about 1500 m above the surface) and 'modified' surface geostrophic trajectories (see Smith and Jeffrey, 1975). The end-points of each of the back trajectories are classified according to "sector of origin" each sector being 45° in width and centered on one of the eight points of the compass. In addition, an unknown sector is included to handle cases where trajectories meander over two or more sectors or back trajectory end-points are very close to the receptor, etc.

3.2. Synoptic Weather Classification System

In order to study the relationship between synoptic weather patterns and measured pollutants, the eight classes defined by Heidorn (1979) to categorize the daily weather patterns were used. They are: Class 1: Post-cold front/pre-high pressure ridge. Class 2: High pressure ridge. Class 3: Post-ridge/pre-warm front. Class 4: Warm front. Class 5: Cyclonic. Class 6: Cold front. Class 7: Stationary front. Class 8: Weak pressure gradient.

4. SUMMARY OF FINDINGS

4.1. Long-term studies

Long-term studies of acidic precipitation in Ontario using meteorological analysis have only been conducted in recent years. One of the earliest works is that of Kurtz and Scheider(1981) which is based on measurements of pH, SO_4^{-2} and NO_3^- over a 33 mo period from August 1976 to April 1979 in the Muskoka-Haliburton region of Ontario. Sea-level geostrophic trajectories were used to determine the 'octant of origin' of the air mass associated with precipitation events. The study indicated that precipitation events most commonly occurred with trajectories from the south and southwest octants. In addition, the majority of H^+, SO_4^{-2} and NO_3^- deposited at Muskoka-Haliburton was associated with trajectories from the south and southwest. It was also noted that the average concentrations of H^+, SO_4^{-2} and NO_3^- in precipitation from the S, SW, W and NW octants are all substantial.

Since that initial study, air parcel trajectory analyses of precipitation data collected at locations in southwestern, central, eastern and northwestern Ontario have been conducted for the period July 1980-April 1983 in attempts to relate the wet deposition of various chemical species to octant of air mass origin and to study the

effects of Sudbury emissions on precipitation quality (Kurtz, 1983; Yap and Kurtz, 1984). These studies suggest that southeast through southwest air flows are associated with about 60 to 80% of the wet deposition of sulphate and nitrate in Ontario. Loading contributions vary somewhat according to location and according to length of trajectory. Mean event loadings are also highest for airflows from the southerly sectors.

Application of this simple back-trajectory analysis to study the impact of the shutdown of Sudbury smelters on wet deposition in Ontario, however, gave, inconclusive results because of large meteorological induced variability in the precipitation chemistry and wet deposition data, and the fact that the smelter contribution was typically less than 15% at the receptors (Lusis, 1984).

These long-term trajectory studies suggest that southwesterly air reaching Southern and Central Ontario has previously passed over the industrialized Ohio Valley which is heavy in SO_x and NO_x emissions and has often traversed over industrialized regions of southwest Ontario as well. Such air is generally associated with more precipitation than air from other directions. This can be seen from synoptic meteorological consideration. For example, synoptic classes 3, 5 and 1 were most frequently associated with precipitation at the Dorset, Longwoods, Railton and Fernberg sites. These are, respectively: pre-warm front, cyclonic and post-cold front situations. The first two are associated with generally southerly winds and the last is associated with north or northwesterly winds behind the winter cold front. By far, most of the precipitation was associated with classes 3 and 5.

4.2. Episodic Study

During the period August 28-September 4, 1981, an acidic deposition episode occurred at Dorset in the ecologically sensitive Muskoka-Haliburton area of Ontario. The analysis of this event is reported by Kurtz et al., (1984). This eight day study period was characterized by 12% of the total 1981 precipitation, 28% of both the annual H^+ and SO_4^{-2} deposited at Dorset and 16% of the annual NO_3^- deposited at Dorset.

The analysis indicated that wet deposition of S and N was associated with air trajectories from the southwest, which is the direction of the Ohio Valley industrial source region, as well as industrialized southwestern Ontario. High air concentrations of S and N were also associated

with trajectories from the southwest and appeared to be partly related to precipitation intensity. It was also suggested that episodic storms can have at least as great an impact on stream pH depression as snowmelt and spring runoff.

5. CONCLUSIONS

The potential source regions of acidity in Ontario have been investigated in recent years using a meteorological data acquisition system, air parcel trajectory techniques and a synoptic weather classification system. These meteorological studies indicate that most of reported wet deposition of S and N in South and Central Ontario is associated with trajectories from the south to southwest octants, the direction of the Ohio Valley and industrialized SW Ontario. In addition, high air concentrations of S and N are also associated with trajectories from these octants.

REFERENCES

Chan, W.H., Orr, D.B and Vet, R.J.: 1982a, "An Overview: The Event Wet/Dry Deposition Network", Ontario Ministry of the Environment Report ARB-11-82-ARSP.

Chan, W.H., Orr, D.B. and Vet, R.J.: 1982b, "An Overview: The Cumulative Wet/Dry Deposition Network", Ontario Ministry of the Environment Report ARB-15-72-ARSP.

Heidorn, K.: 1979, Water, Air and Soil Pollution, 11, 225.

Kurtz, J.: 1983, "Meteorological Analysis of Precipitation Event Sampling Data", Ontario Ministry of the Environment Report ARB-198-84-AQM.

Kurtz, J. and Scheider, W.A.: 1981, Atmos. Environ., 15, 1111.

Kurtz, J., Tang, A.J.S., Kirk, R.W. and Chan, W.H.: 1984, Atmos. Environ., 18, 387.

Lusis, M.: 1984, "Summary: Source Apportionment Analysis of Air and Precipitation Data to Determine the Contribution of the Sudbury Smelters to Atmospheric Deposition in Ontario", Ontario Ministry of the Environment Report ARB-194-84-ARSP.

Smith, F.B. and Jeffrey, G.H.: 1975, Atmos. Environ., 9, 643.

Yap, D. and Kurtz, J.: 1984, "Meteorological Studies to Quantify the Effects of Sudbury Emissions on Precipitation Quality and Air Quality During 1980-1983 with Emphasis on the Shut-Down Period", Ontario Ministry of the Environment Report ARB-192-84-AQM.