Case Study of a Trans-Boundary Air Pollution Event in Nova Scotia, June 9-10, 2004

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Abstract

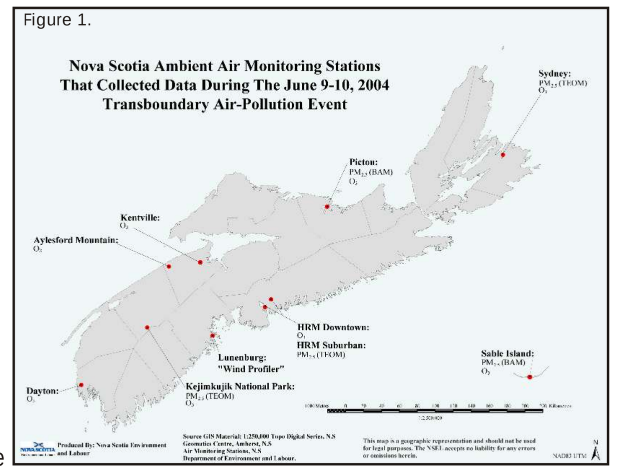
Continental air masses that travel over heavily populated and industrialized regions of eastern Canada and the north-eastern United States carry with them various air pollutants such as ground-level ozone (GLO) and its precursors, and fine particulate matter (PM2.5). Nova Scotia Environment and Labour (NSEL) and the Meteorological Service of Canada (MSC) have a combined network of five continuous $PM_{2.5}$ monitors and eight GLO monitors in Nova Scotia. On June 9 and 10, 2004, the network recorded an episode of degraded air quality that encompassed the entire province. By utilizing the MSC's back-trajectory model, $PM_{2.5}$ and GLO data, and meteorological data, we found that the source of this event was an air mass that had stagnated over New England, was photoreacted and then transported over Nova Scotia. We also found evidence in 'wind-profiler' data that polluted-air transported at a higher altitude from the Great Lakes region can be mixed at lower altitudes over Nova Scotia.

In addition to the synoptic event clearly seen in the data, questions arose about variability in adjacent data points in the $PM_{2.5}$ data. We believe that particulate clouds are heterogeneous in composition; thus giving, at times, high variability between adjacent hourly-averages. Because elevated $PM_{2.5}$ events can be regional and particulate monitors are used to represent an extended area from the monitor, further investigation into mixing and deposition related to particulate and meteorological interactions would be valuable for inferring spatial representation of particulate monitors.

Instrumentation

The air-monitoring network in Nova Scotia had eight ground-level ozone (GLO) and five fine-particulate (suspended particulate smaller than 2.5 µm in diameter) ($PM_{2.5}$) monitors (Fig.1) operational throughout the period of study, all either owned and/or maintained by Environment Canada or Nova Scotia Environment & Labour (NSEL). Data from a "wind profiler" (Fig. 20) located in Lunenburg was also utilized in the study.

Figure 1.



Two different measurement technologies were used to collect $PM_{2.5}$ data (Fig.2): the Tapered Element Oscillating Microbalance (TEOM, Rupprecht & Patashnick, Model 1400A) and the Beta Attenuation Method (BAM, Met One Instruments, Model 1020). For this study the TEOM and BAM data are taken to be comparable to each other even though they measure $PM_{2.5}$ by two different methods. Ozone (Fig.3) was measured by ultraviolet absorption by five Thermo Environmental, Model 49-C; and two Monitor Labs, Model 8810 analyzers. The wind profiler was a Vaisala LAP-3000, a low-power Doppler radar that measured signal return strength of 915 MHz radio waves.

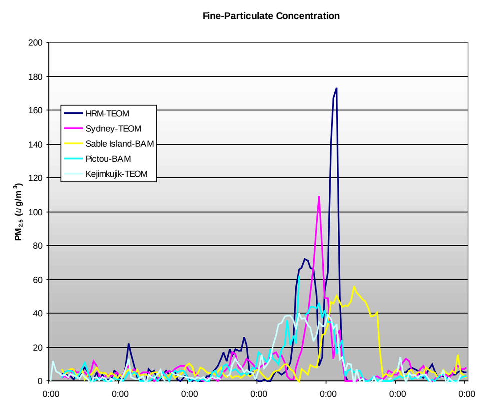


Figure 2.

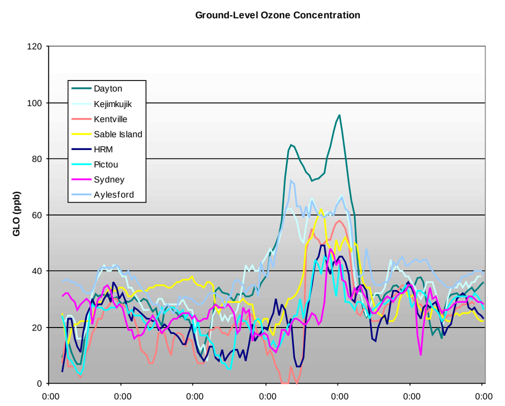


Figure 3.

Figure 4.
AQUA Modis Visible Satellite Image[3] – 1730UTC, June 9, 2004.

Note the 'hazy' conditions due to the elevated particulate matter content, extending through the bottom half of the image – from Central New Brunswick and south. Also note the absence of fog around coastal Nova Scotia – important when considering wind profiler data.

Nova Scotia Environment and Labour

Time-series snapshots of the mean sea-level pressure patterns, time-series graphs of the $PM_{2.5}$ and GLO concentrations at Halifax (chosen because of it's central location in the province) along with the corresponding back-trajectories at 1000 and 925 hPa from June 8, 1200 UTC to June 10, 0600 UTC.

The 72hr back-trajectories were calculated using the Meteorological Service of Canada's hemispheric trajectory model[1] using 1000, 850, 700 and 500 hPa 2D wind data. The triangles or squares represent the parcel location every 6 hrs. Altitude of the parcel is indicated below the trajectory map. 950 hPa trajectories are Red and 1000 hPa are Blue.

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June 8, 2004, 1200 UTC

Note the ridge extending over the emission areas of the eastern US from a 'Bermuda High' providing stagnant conditions, light winds, sunny skies and temperatures around 30°C (Fig. 5). Stagnation of air and photoreaction of pollutants over the emission areas occurred. Concentrations in Halifax (HRM) leading up to this time have been insignificant (Fig. 6).

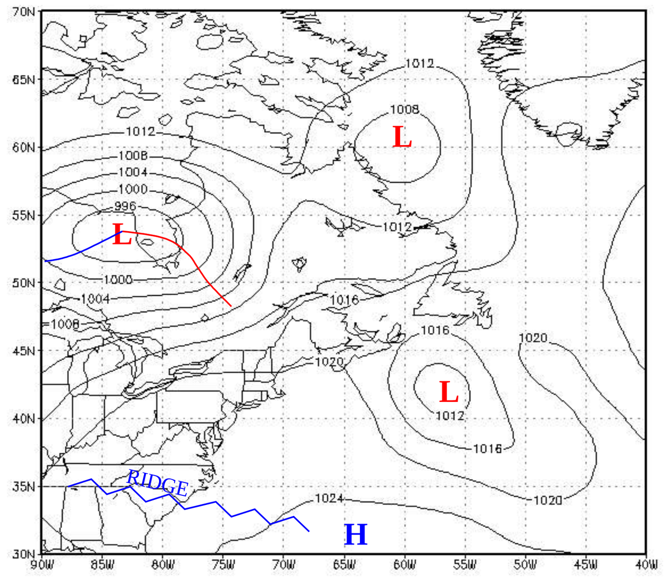
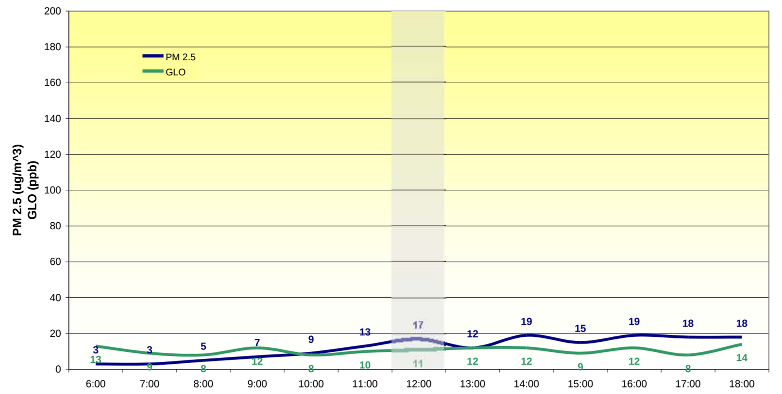


Figure 5.



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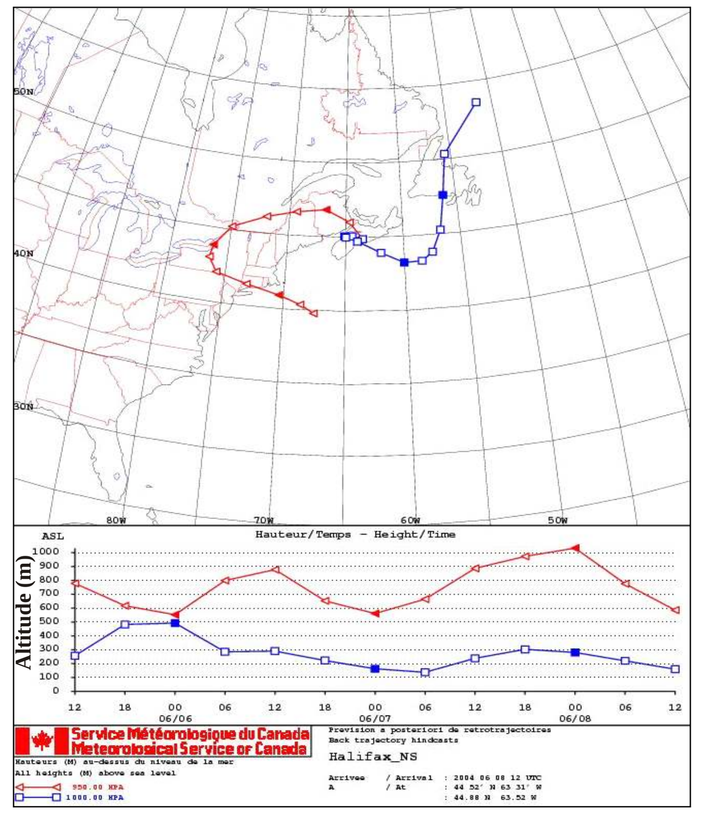
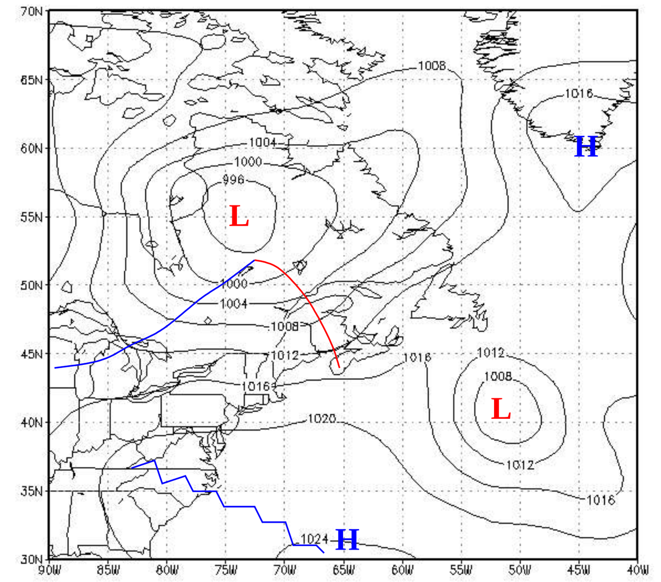


Figure 7.

June 9, 2004, 0000 UTC

A Ridge of high pressure began to pull away from the emission areas. Transport of the 'polluted' air commenced as winds increased over the emission areas in advance of the approaching trough and cold front (Fig. 8). Concentrations of pollutants in Halifax were still insignificant (Fig. 9).



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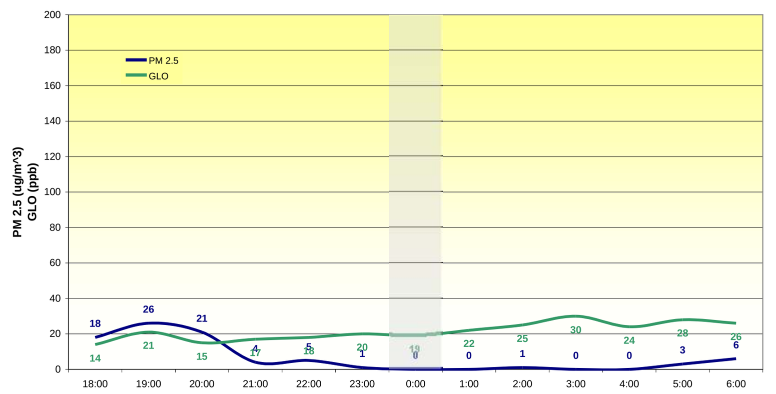

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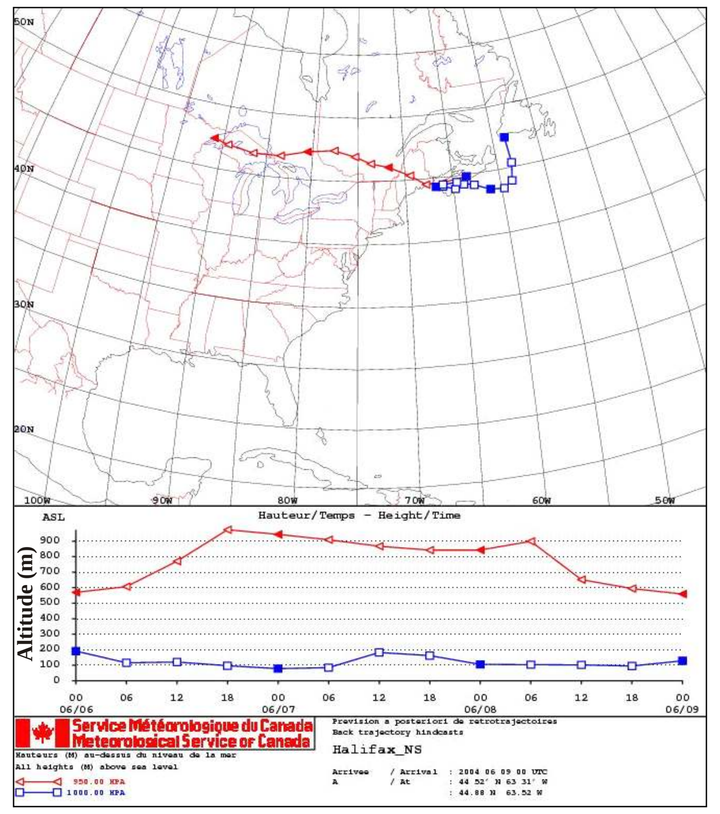


Figure 10.

June 9, 2004, 1800 UTC

A trough and cold front that stretched from the Great Lakes region to just South of Labrador brought with it pollutants in advance of the front (Fig. 11). A peak in the GLO and $PM_{2.5}$ concentrations was recorded (Fig. 12). At this time, the wind profiler at Lunenburg indicated an increase in mixing height (Fig. 20), thus pollutants from 1000 hPa and 950 hPa were mixed at ground-level (Fig. 13). Hazy conditions at this time can also be seen in the satellite image (Fig. 4).

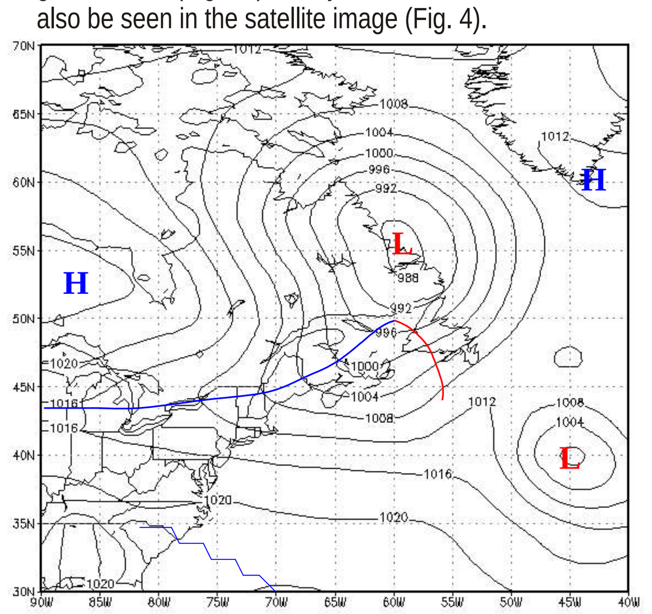
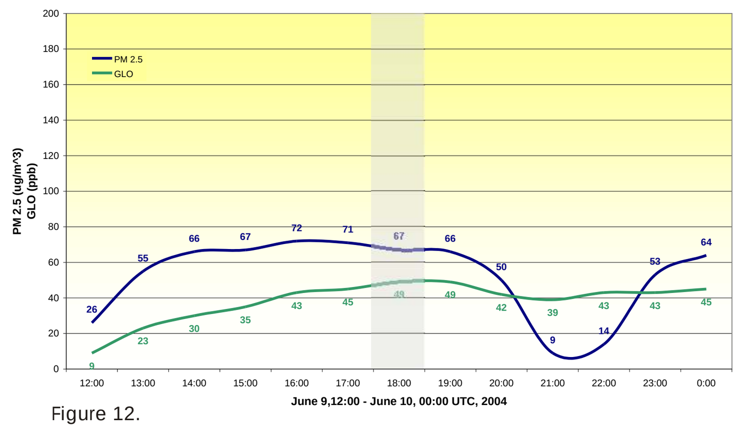


Figure 11.



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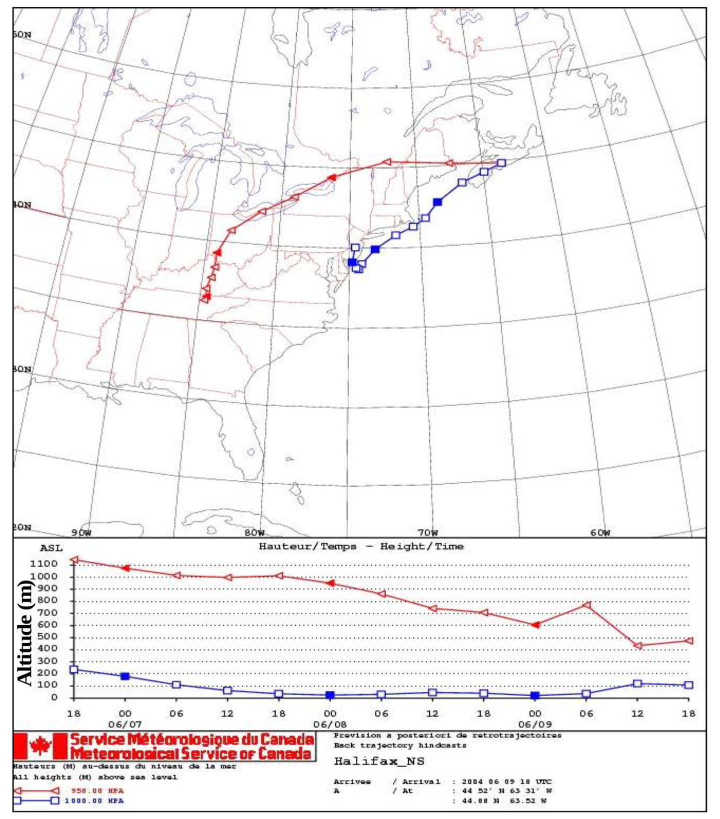
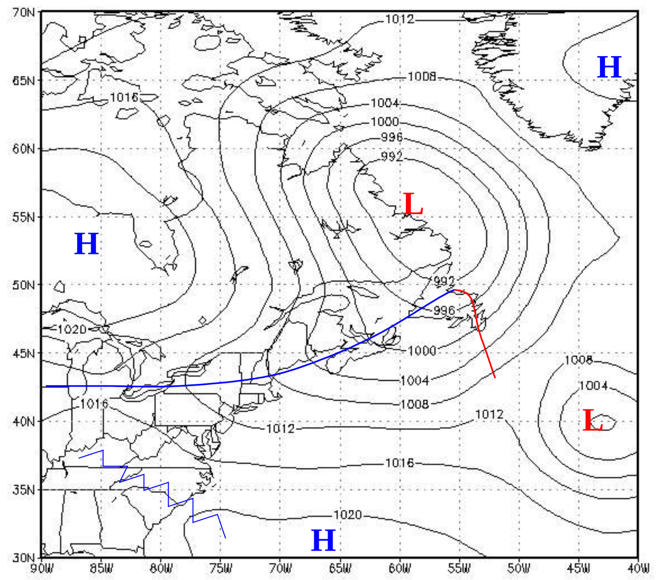


Figure 13.

June 10, 2004, 0000 UTC

The front passed through Kejimkujik, Halifax, and Sydney at about the same time (Fig.14). Peak $PM_{2.5}$ values were reported just in advance of the cold front (Fig.15). Mixing heights from the wind-profiler data decreased (Fig. 20) and back-trajectories from the New England area were most significant at this time (Fig. 16).



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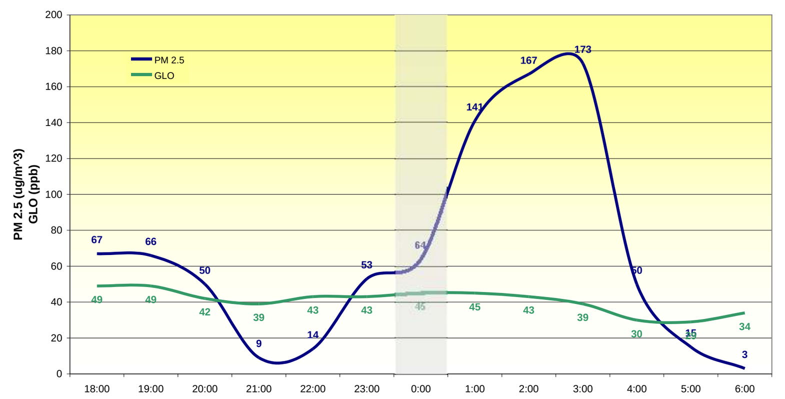

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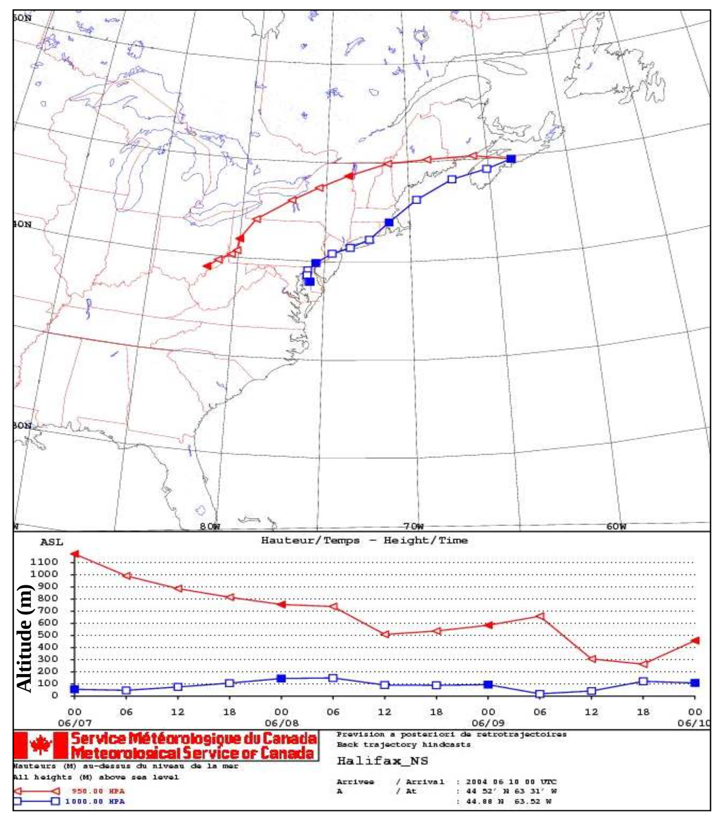


Figure 16.

June 10, 2004, 0600 UTC

The cold front passed over Halifax (Fig. 17) and a north-westerly flow brought 'clean' air to the area resulting in a sharp decrease in $PM_{2.5}$ measurements (Fig. 18). Back-trajectories were from the northwest (Fig. 19).

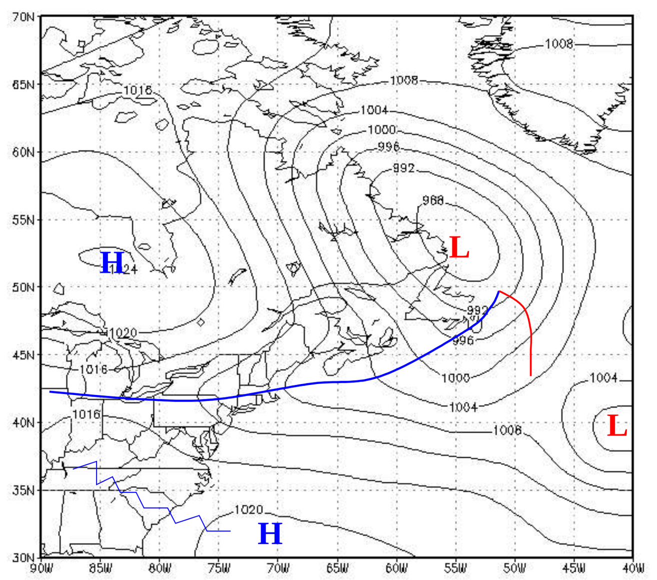


Figure 17.

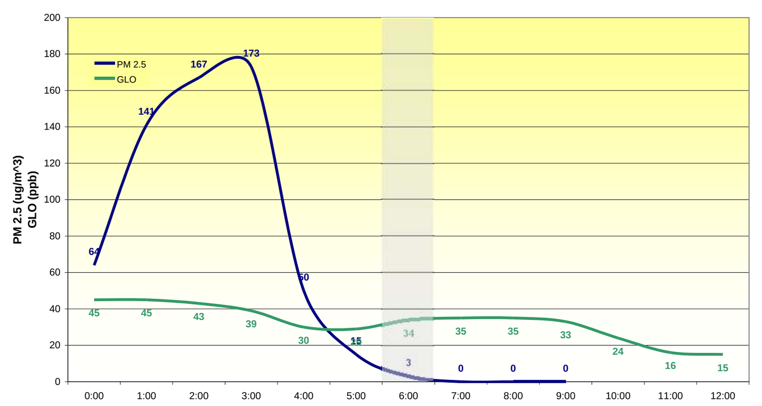
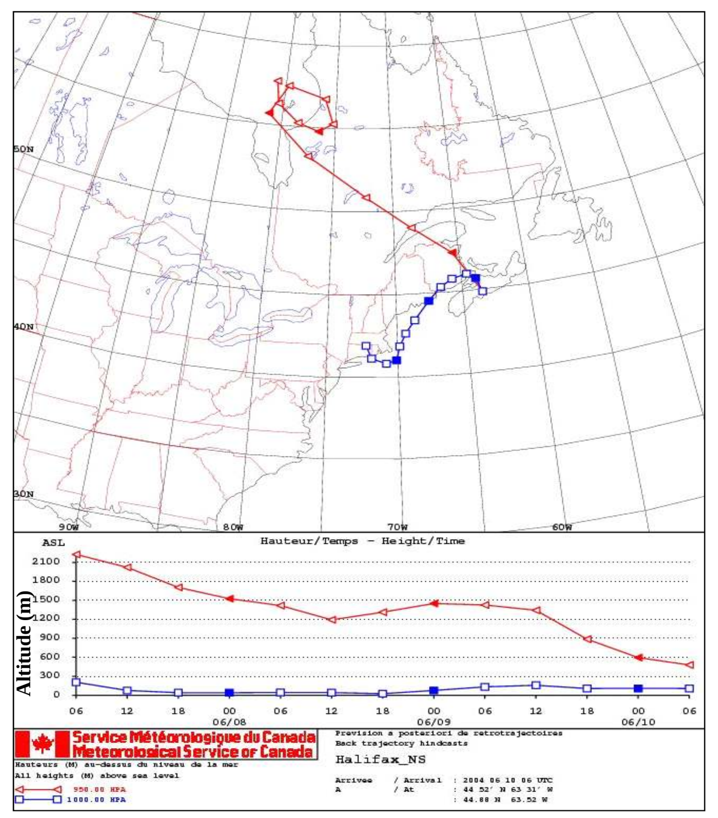


Figure 18.



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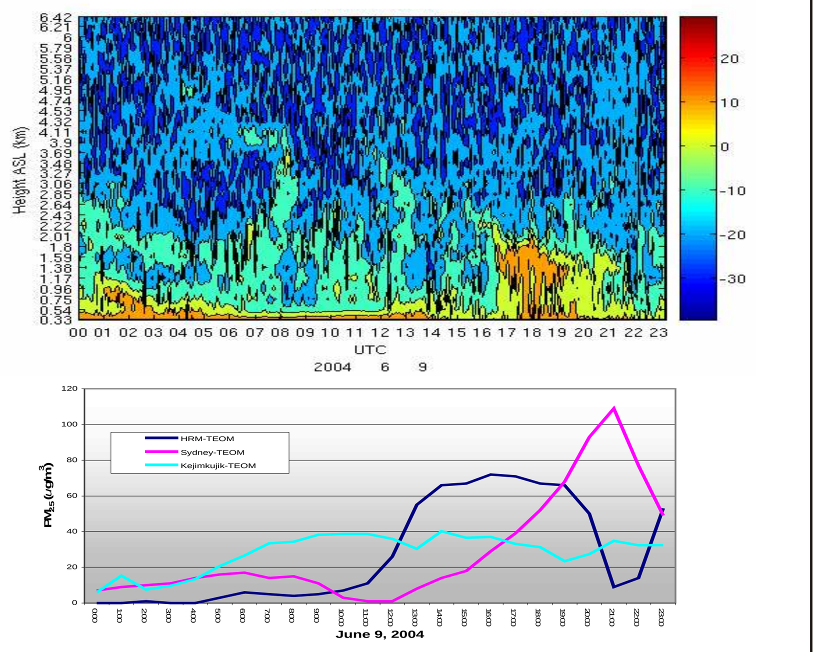

Figure 20. Lunenburg Bay Wind Profiler Signal-to-Noise Ratio for June 9, 2004 and hourly $PM_{2.5}$ concentrations at Kejimkujik, Sydney and Halifax.

A strong signal-to-noise ratio (SNR) during the period 1700-2100UTC indicates a mixing height of about 2 km when $PM_{2.5}$ concentrations were elevated[2]. An approaching front passed over Halifax, Sydney, and Kejimkujik at essentially the same time so that the profiler data are expected to be somewhat representative of the province at that time. Shown here is the $PM_{2.5}$ for Halifax, Sydney and for Kejimkujik National Park. The increase in $PM_{2.5}$ concentrations is possibly a result of enrichment from particulate transported at higher altitude (950 hPa) from the Great Lakes region (Fig.13). A sharp decrease in signal return at 2200UTC is also seen to correlate with a decrease in Halifax's $PM_{2.5}$ data at the same time. Also, the low mixing height at 1600UTC correlates with a decrease in particulate at Kejimkujik. However, a steep peak in Halifax's $PM_{2.5}$, on June 10, 0300UTC, just as the front passed, does not show a corresponding rise in mixing height (not shown). It is hypothesized that the first peak was a result of particulate transported from both the New England States and the Great Lakes region being mixed in advance of the front. However, as the front was impending, mixing ceased and particulate at 1000 hPa were 'pushed' into a higher concentration and over the monitoring stations.

Discussion

The data analyzed for the June 9 and 10, 2004, smog event in Nova Scotia clearly show meteorology-driven transport of pollutants into Nova Scotia. The events contributing to the nature of Nova Scotia's degraded air quality (stagnation and photoreaction over emission areas, a Bermuda High, pollutant transport along an occluding front, 'clearing-out' with front passage) are typical for the warmer months seen from April into October, and much can be learned from this event to further understand air quality in Nova Scotia.

This event is of special interest for a couple of reasons. First, continuous $PM_{2.5}$ measurement does not have a long history in Nova Scotia, and this is the first time that five instruments have been able to capture a record of such an event. There have been past events, but limited data have impaired detailed analysis. However, a brief examination of the historical data available has shown similar trends that may not have been apparent without the current data analysis. The dual-peak characteristic of the $PM_{2.5}$ (most strongly seen in the Halifax data) (Fig. 2), for example, is also seen to some extent in the historical data. Future work will be done to understand this phenomenon.

Secondly, the cold front passed over the length of Nova Scotia, and so several stations strung out across the Province, at about the same time. The position and timing of the front passage allows for inter-comparison of data sets regardless of their location. From this, we were able to find a relationship between mixing height and pollutant concentration, thus giving evidence for pollutant origins from the Great Lakes region and from New England being mixed over Nova Scotia. Also, the data give evidence for $PM_{2.5}$ being 'piled-up' by a cold front as it advances on the occluding warm sector. Future analysis of frontal mechanics combined with this data may lead to greater understanding of pollutant behaviour.

The timing of the front passage may also prove useful for determining the spatial representation of particulate monitors, which until now has proved difficult to determine. A particulate monitor on its own averages air passing over the monitor for the previous hour. Within that hour, there may be microscale and mesoscale influence and mixing, thus resulting in heterogeneous particulate concentrations. Often, however, the data are inferred to be representative of a larger area. From this data set, spatial correlation between the monitors may help determine the geographic scale that may be inferred from the monitor.

Acknowledgements

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Weather charts courtesy of the US National Weather Service.

References

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3. Modis Rapid Resonse System, http: //169.154.196.76/realtime, National Aeronautics Space Administration - Goddard Flight Space Center, 2004, accessed August, 2004.