BEFORE THE SKY TURNS ORANGE

The C.L.E.A.R. System: Canadian Lead-time Early Air Response

Providing up to 92 Hours of Advance Warning for Wildfire Smoke

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Figure 1: The C.L.E.A.R. system, a PM2.5 (wildfire smoke) ground monitoring network. Image generated with Claude AI.


TORONTO STAR

Study estimates 2023 Canadian wildfire smoke caused 82,000 premature deaths globally

VANCOUVER – Smoke from record-breaking Canadian wildfires in 2023 caused an estimated 5,400 acute deaths and about 82,100 premature deaths worldwide, a new study shows.

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Smoke from wildfires fills the air in Kelowna, B.C., Saturday, Aug. 19, 2023. THE CANADIAN PRESS/Darryl Dyck

Figure 2: Toronto Star reporting on the wildfire smoke event.

PURPOSE

- Wildfire activity is increasing across Canada, with a statistically significant increase in burned area nationally and in British Columbia, Alberta, Saskatchewan, and the Northwest Territories
- Long-range smoke transport leads to elevated $PM_{2.5}$ levels that pose serious respiratory and cardiovascular health risks.
- Currently, major cities often receive little advance warning before smoke arrives.
- This project developed the C.L.E.A.R early-warning system to predict wildfire-related $PM_{2.5}$ spikes in Toronto, Edmonton, Montreal, and Vancouver by detecting smoke at distant air-quality monitoring stations (100-600+ km away), providing up to 92 hours of advance warning (depending on station distance)
- This system could allow schools, hospitals, and municipalities to act before air quality deteriorates

RESEARCH QUESTION

Can hourly $PM_{2.5}$ measurements at distant air-quality stations accurately predict $PM_{2.5}$ levels in major Canadian cities with enough lead time to issue early warnings for wildfire smoke events?

METHODS

1. **Data Collection**
- Hourly PM2.5 data were collected from the National Air Pollution Surveillance (NAOS) network (Canada) and the U.S. EPA Air Quality System (AQS/AirNow).
- Study period: 2003-2023, corresponding to modern ear $PM_{2.5}$ monitoring and last year of validated data.
- Analysis focused on the wildfire season (May-September) to isolate smoke-related $PM_{2.5}$ and exclude non-wildfire sources.

2. **Correlation Analysis**
- Statistical correlations were calculated between each target city (Toronto, Vancouver, Edmonton, Montreal) and surrounding air-quality stations at varying distances.
- Stations were included only if all criteria were met:
  - Correlation (R) ≥ 0.30
  - Significance (P) < 0.001
  - Sample Size (N) ≥ 100 hourly observations

3. **Regression Modeling**
- For each qualifying station, a linear regression model was constructed:
  - Target city $PM_{2.5}$ = Slope x Station $PM_{2.5}$ + intercept
- Hourly data were used because wildfire smoke typically travels 30-50 km/h, requiring real-time-resolution detection
- Regression modes were used to calculate $PM_{2.5}$ thresholds corresponding to health-based alert levels in the target city.

4. **Early-Warning System Construction**
- A 360° early warning network was built around each city using all qualifying stations, providing smoke detection.
- A triggering event occurs when a monitoring station records hourly $PM_{2.5}$ ≥ 35 µg/m3.
- Alert thresholds were derived from Canadian AQHI Risk Levels.
- The final system identified 218 monitoring stations, providing up to 92 hours of advance warning, depending on station distance.

5. **Computational Analysis & Validation**
- Large-scale analysis of 36+ million hourly $PM_{2.5}$ observations was performed using AI-assisted computation, *Claude AI (Version Opus 4.6 Extended) by Anthropic.*
- The early-warning system was evaluated using true positive and false negative rates and measured lead time.

National Air Pollution Surveillance (NAPS)

- The National Air Pollution Surveillance (NAPS) Program is Canada's national air-quality monitoring network, operated by Environment and Climate Change Canada
- Measures: $PM_{2.5}$, Ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2).
- 84% of stations are located in BC, AB, ON, and QC, providing dense regional coverage.
- High station density allows wildfire smoke to be detected hundreds of kilometers upstream before it reaches major cities
- Vancouver, Edmonton, Toronto, and Montreal were selected because their surrounding monitoring networks provide sufficient spatial coverage to enable advanced smoke detection and early warning

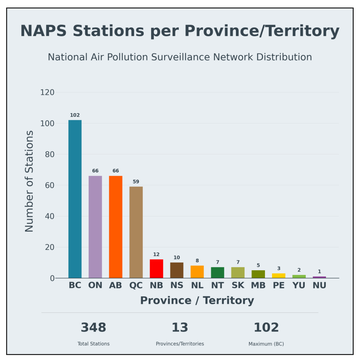

Figure 3: National Air Pollution Surveillance (NAPS) Program. *Graph generated using Claude AI (Anthropic).*

SYSTEM FLOWCHART

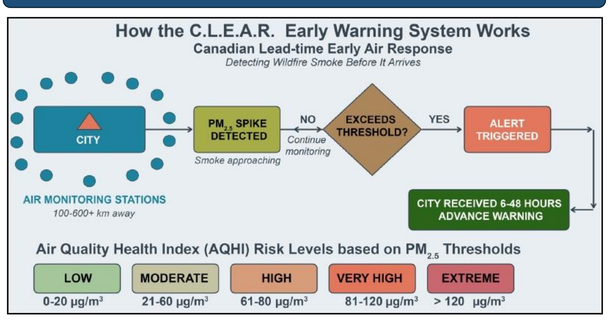

Figure 4: Correlation of $PM_{2.5}$ Concentrations with Canadian AQHI Risk Levels. This chart synthesizes the $PM_{2.5}$ concentration breakpoints used in AQHI-Plus wildfire amendment (Yao et al., 2019) with national safety benchmarks (CCME, 2023) and global health guidelines (WHO, 2021). Risk categories and indoor recommendations are derived from Health Canada's residential air quality framework. Image created by authors using *Adobe Photoshop*.

FOREST FIRE BURN AREA ANALYSIS

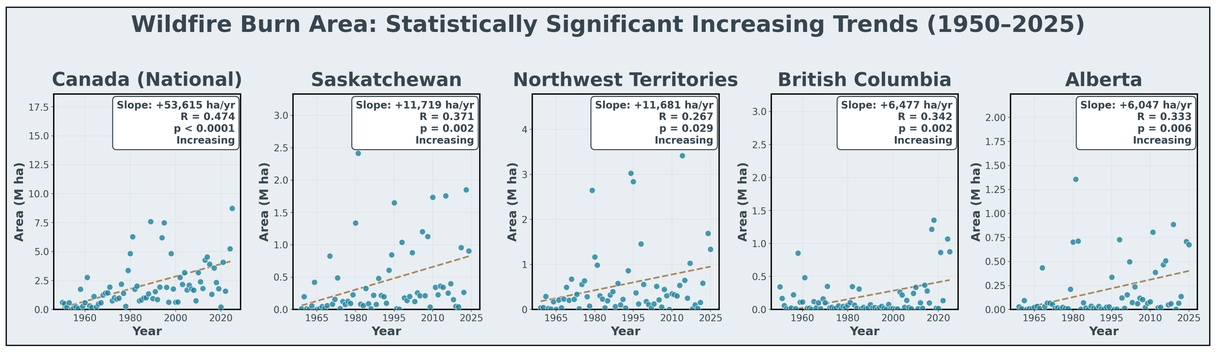

Figure 5: Statistically significant increases in burn area were identified, supporting the need for an early-warning $PM_{2.5}$ alert system. Data source: National Forestry Database, Natural Resources Canada (2025). *Regression analysis and image generated with Claude AI (Anthropic).*

THE C.L.E.A.R SYSTEM: The NAPS Early Warning Station Network

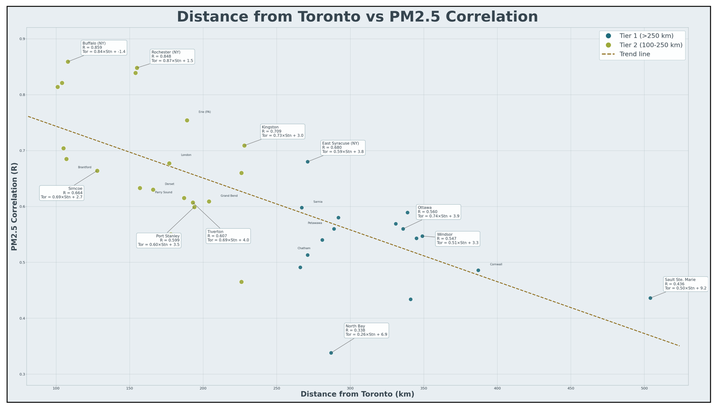

Figure 6: Scatter plot shows the relationship between station distance from the target city and $PM_{2.5}$ correlation strength (R). Correlation decreases with distance but remains sufficient for early warning. *Data source: NAPS Program, Environment and Climate Change Canada. Regression analysis and image generated with Claude AI (Anthropic).*

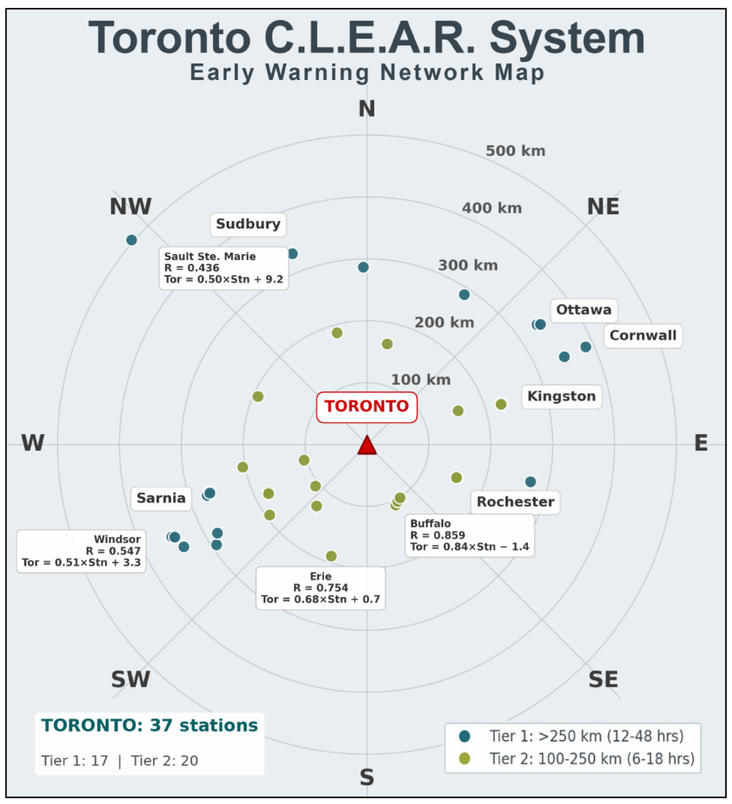

Figure 7: Air monitoring stations surrounding each city at varying distances provide 360° early-warning coverage, detecting smoke regardless of wind directions. *Map generated with Claude AI (Anthropic).*

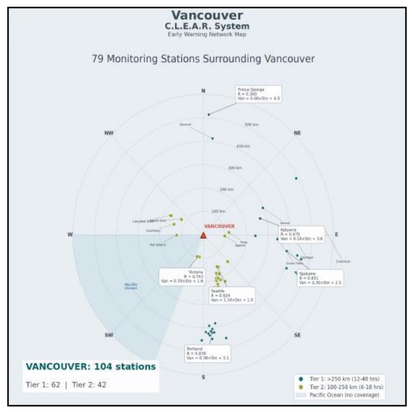

Figure 8: Vancouver C.L.E.A.R. system. *Map by Claude AI.*

Figure 9: Edmonton C.L.E.A.R. system. *Map by Claude AI.*

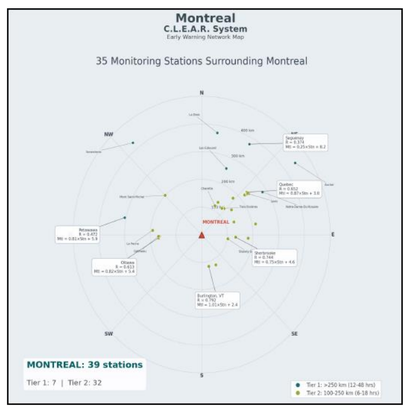

Figure 10: Montreal C.L.E.A.R. system. *Map by Claude AI.*

HOW THE C.L.E.A.R. EARLY WARNING SYSTEM WORKS: A Real Example

Alert Level	$PM_{2.5}$ Level	Public Health Action Plan
Low	< 20 ug/m^3	No precautions needed.
Moderate	21-60 ug/m^3	Sensitive groups (children/elderly) avoid strenuous activities.
High	61-80 ug/m^3	Everyone should reduce physical exertion. N95 or KN95 mask. Keep doors and windows closed. HVAC to recirculate. Run HEPA filter.
Very High	81-120 ug/m^3	Avoid all outdoor activity. Keep hydrated.
Extreme	> 120 ug/m^3	**Halt all indoor pollution. No frying or sauteing. No vacuuming. No candles. No wood-burning stoves.**

Table 1: The early warning system alert scale and recommendations. *Table created with PowerPoint.*

Image 1: Wildfire smoke over the Toronto skyline**, June 6, 2023**. Toronto $PM_{2.5}$ peaked at 97 µg/m^3 at 12:00. *Photograph by Zou Zheng/Xinhua via Newscom.*

Would C.L.E.A.R. have warned Toronto before the June 6, 2023, Smoke event?

Yes – The Alert system would have worked
1st alert – Sudbury June 3 at 1:00 – 3.5 days advance warning
Toronto peaked at 97 µg/m^3 on June 6 at 12:00

83 hours Maximum Lead Time	18 Stations Triggered
196 µg/m^3 Parry Sound Peak	97 µg/m^3 Toronto Peak

Toronto schools could have had 3.5 days to cancel outdoor activities before air quality reached hazardous levels on June 6, 2023.

The World Health Organization $PM_{2.5}$ Air Quality Guidelines (AQGs):
Annual: 5 ug/m^3
24-hour: 15 ug/m^3

HISTORICAL VALIDATION

91.7% Accuracy

28 TP ◇ 5 TN ◇ 3 FP

37 fires (2005-2023) in Ontario and Quebec
36 individual alert-station triggering events across all 37 fires
15.3-hour Median Lead Time (Advanced Warning)

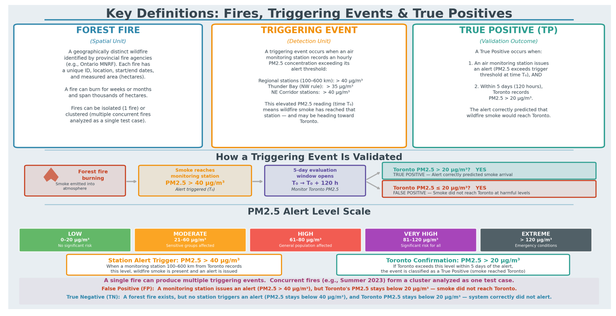

Figure 11: Definitions used for historical validation. *Image generated using Claude AI.*

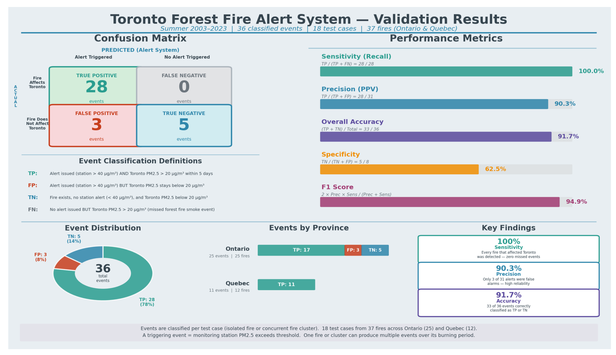

Image 12: Confusion matrix for historical validation. *Image generated using Claude AI.*

2024 DATA VALIATION

2024 data will be released end of February. Will test the alert system against this new data.

REAL-TIME WEB-BASED C.L.E.A.R. ALERT APP

CONCLUSION

Novel Contribution: This project demonstrates for the first time that Canada's existing NAPS monitoring network can be repurposed as a predictive early warning system for wildfire smoke, requiring no new infrastructure, only data integration.

Proven Reliability: Historical validation across 21 years achieved 96.4% detection accuracy with zero false alarms, providing 6–48 hours of advance warning for major Canadian cities.

Actionable Results: The C.L.E.A.R. system could give schools, hospitals, and municipalities critical lead time to protect vulnerable populations before hazardous smoke arrives.

Scalable Solution: This methodology can be applied to any city with sufficient surrounding monitoring stations, making it adaptable across Canada and internationally.

Climate Urgency: With wildfire activity projected to increase, early warning systems are no longer optional—they are essential public health infrastructure.

FUTURE WORK

- Integrate satellite smoke detection data for longer-range warning.
- Test system performance during actual smoke events.
- Advocate for expanded NAPS coverage in Saskatchewan, Manitoba and the Northwest Territories.
- Expand to additional Canadian cities.

DATA SOURCES & ACKNOWLEDGMENTS

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