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ESTIMATING THE AIR QUALITY IMPACTS OF FOREST FIRES IN ALBERTA

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1.0 INTRODUCTION

Levelton Consultants Ltd. (Levelton) was retained by Alberta Environment (AENV) in collaboration with Sustainable Resource Development (ASRD) to evaluate the impacts of two forest fires in Alberta.

Forest fires in Alberta have been estimated to result in significant emissions of pollutants which consequently can have considerable impacts on air quality, possibly leading to potential health risks. There are many pollutants released through forest fire combustion including carbon monoxide (CO), nitrous oxides (NOx), volatile organic carbons (VOC), ammonia (NH_3), small amounts of sulphur dioxide (SO_2), and particulate matter (PM) (US EPA, 2002). PM is of particular interest due to significant health (respiratory irritations) and environmental (reduced visibility) effects associated with high ambient concentrations. Forest fires release PM less than 10 microns (PM_{10}), and PM less than 2.5 microns ($PM_{2.5}$) directly into the atmosphere. Additionally PM is formed as gaseous pollutants released from the fire react in the atmosphere.

In order to evaluate air quality and determine potential health risks from forest fires, the shape and trajectory of the forest fire smoke plume, as well as measurements of ground level concentrations of the pollutant(s) of interest must be known. A dispersion model CALPUFF was used as analysis tool and modelling results were used to determine how the forest fire plume behaved throughout the duration of the fire. Terrain data, meteorological data, and fire specific information was used in the model. In order to validate the dispersion model results, comparisons with ambient particulate matter concentrations and MODIS satellite imagery data were made. One objective of the project was to determine whether this approach could be applied to other fires, or if the approach could be adapted for use as a forensic or forecasting tool in the future.

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2.0 METHODS

In order to provide a quantitative estimate of the impact of forest fire emissions on local and regional air quality a general methodology was followed. The steps are explained in the following sections.

2.1 *Identification of a suitable fire*

In order to model a fire, determine its emissions, and evaluate the model, a candidate fire must have had the following features:

1. Observations of the plume. This could take the form of:
   (a) ambient air quality data with at least some elevated concentrations of carbon monoxide, particulate matter, sulphur dioxide and/or nitrogen oxides measured in the vicinity of the fire, during the fire period.
   (b) satellite imagery or interpreted image data that could identify the plume and the direction of plume dispersion.
2. Reasonably representative meteorological data (e.g. on-site hourly) from at least one nearby weather station during the time of the fire.
3. Fire environment data (fuel, topography) and fire progression data must be available.

Based on these criteria, two case studies were identified: "The Chisholm Fire", (May 2001) and "The Lost Creek Fire" (July-August 2003).

2.1.1 *The Chisholm Fire*

The Chisholm fire (Identified as LWF-063) ignited on the evening of May 23rd 2001 (at approximately 21:35), just north of Flatbush Alberta, near a Canadian National railway line. The fire was human induced. Meteorological conditions leading up to the start of the fire included lower than average precipitation throughout the winter and the spring; moisture content of the soil was low. Fuels in the Chisholm fire area consisted of black and white spruce conifers and deciduous timbers.

Foliar moisture content of the conifers was at its annual low, deciduous grasses and herbaceous plants were still dormant, but overstory green-up had occurred in deciduous timbers. The terrain in the area was relatively flat allowing the fire to grow quickly in the direction of the wind. The Chisholm fire exhibited extreme fire behaviour including rapid spread rates, continual crown fire development, medium to long range spotting, large convective clouds, and firewhirls. The final area burnt exceeded 116,000 ha of land.

The Chisholm fire has been well documented and additional information can be found in the *Final Documentation Report - Chisholm Fire* (LFW-063) (ASRD, 2001a,b,c), as well as the *Chisholm Wildfire Entrapment Investigation* (ASRD, 2001d) and the *Chisholm Fire Review Committee Report* (ASRD, 2001e).

Features of the Chisholm fire that made it applicable for use in this study included:

1. Ambient air quality data with elevated PM concentrations available from stations in Edmonton during the time of the fire.
2. Representative meteorological data available from a number of stations near the fire during the fire period.
3. Fire environment data including fuel type data for the area, topographical information, and shapefiles representing the fire perimeter at various times during the fire.

2.1.2 *The Lost Creek fire*

A second case study was conducted in part to determine if experiences in the estimation of emissions and methodology used with the Chisholm fire were fire specific or had potential for more widespread use.

The Lost Creek fire was detected on the afternoon of July 23rd 2003 (at approximately 14:27), near Crowsnest Pass, close to the BC-Alberta border. The fire was ignited in an area of mountainous terrain and containment of the Lost Creek fire was complicated by this factor. The fire continued to grow until mid-August, and by the time the fire stopped burning, over 21,000 ha of land was destroyed. Compared to the Chisholm fire, the Lost Creek fire burnt over a longer period of time, but less land was destroyed.

The Lost Creek fire was selected because it had the following features:

1. Representative meteorological data available from a number of stations near the fire during the fire period.
2. Fire environment data including fuel type data for the area, topographical information, and shapefiles representing the fire perimeter at various times during the fire.

2.1 *Determination of emissions*

The most common and general approach used to determine forest fire emissions considers the type of fuel burned, the fuel loading, the area burned, the proportion of biomass consumed and the type of fire entailed (crown, surface…). Based on these variables, emissions were calculated as follows:

$$Emissions_{\text{Contaminant}} = A \cdot \left(\sum_i F_L \cdot B_c \right) \cdot EF$$

where:

- A = Area burned [ha];
- F_L = Mass of fuel type "I" per area (Fuel Loading) [kg/ha];
- B_c = Consumption factor of fuel type "i";
- $F_L \cdot B_c$ = Biomass consumption;
- EF = Emission factor for the specific contaminant considered.

The area of land consumed by fire was represented by fire polygons, with each polygon indicating fire progression. Fire polygon shapefiles were supplied by the Alberta Government, in the Wildfire Policy and Business Planning Branch of the Forest Protection Division, through the Department of Sustainable Resource Development.

Biomass consumption estimates for both fires were based on hourly weather data and derived from the Spatial Fire Management System (SFMS) using the Fire Behavior Prediction (FBP) system. Using the SFMS and available shapefiles representing the fire perimeter at various intervals during the fire burn period, the surface fuel consumption (SFC) and crown fuel consumption (CFC) values were generated. Total biomass consumption (TFC) was calculated as the sum of SFC and CFC. The biomass consumption values, area burned, and emissions factors for each pollutant (developed by the U.S. Fire Emissions Joint Forum (FEJF)) were then used to calculate emissions estimates using the above equation.

2.2 *Application of an acceptable dispersion model*

Once emissions were calculated, they were used as the basis of input into the CALPUFF dispersion model. Prior to running the dispersion model, meteorological data was gathered for the period of interest and processed for input into CALMET, a diagnostic meteorological model. CALMET was used to produce all the meteorological parameters required for CALPUFF. Specific attention was given to the wind speed and wind direction grids for the areas of the fire based on terrain and land use data. The CALMET meteorological model required the following input data:

- land use and terrain data;
- surface and upper meteorological data; and
- other parameters that were specific to the application and modelling domain.

The CALPUFF dispersion model utilized the CALMET output in combination with emission rates from the fires to predict concentrations of pollutants in the atmosphere. The predicted concentrations were then compared with ambient air quality data for various averaging periods.

2.2.1 Chisholm modelling

The airshed boundaries in this study were defined by grid coordinates ranging from 240000 to 501000 meters east and 5939000 to 6323000 meters north. This area covers two UTM zones; UTM Zone 11 was converted to UTM Zone 12 coordinates. An area of approximately 261 by 384 kilometers (10,022,400 ha) was modelled. The modelling domain selected for the Chisholm fire extended from the fire location north to Fort McMurray and south to Edmonton. It provided suitable coverage for which to make plume and ambient data comparisons, and the area was large enough that any potential meteorological influences on the airshed would have been included. A 3-km grid resolution was used for the modelling domain.

The Chisholm fire ignited on May 23rd at approximately 21:35 and ended on June 4th, 2001. In this application hourly diagnostic data was generated by CALMET from May 23rd to May 30th 2001. This time period was selected because most of the fire growth occurred during this period, and because high concentrations of $PM_{2.5}$ were recorded at ambient air quality stations during this time. Growth of the fire was based on shapefiles polygons which were simplified into trapezoids for input into the CALPUFF model. A graphical representation of the seven trapezoids used to simulate fire growth is presented in Figure 1. The Chisholm fire was split into an east and west portion separated by the Athabasca river. The polygons representing fire progression on the east side of the river (where the fire started) and the dates and times corresponding to each polygon are as follows:

- blue: May 24 12:00
- lime green: May 25 12:00
- orange: May 26 00:00
- dark green: May 29 00:00

The polygons representing fire progression on the west side of the river are also displayed in Figure 1, and correspond to the following dates and times:

- purple: May 27 20:00
- red: May 28 20:00
- cyan: May 29 00:00

The fire spread rapidly over the period of only a few days.

Five metrological surface stations were selected for input into CALMET. The surface stations included Fort McMurray, Chisholm, Salteaux, Slave Lake and Edmonton. Fort McMurray (to the north) and Edmonton (to the south) were included because ambient air quality data was recorded at these sites. The Edmonton, Fort McMurray and Slave Lake stations are Environment Canada weather stations. Salteux is an automatic weather station run by Alberta Forest Protection (AFP).

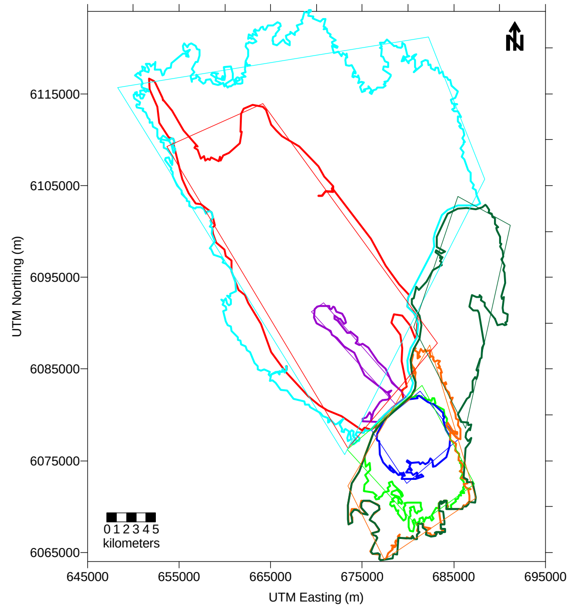


Figure 1. Fire growth polygons for the Chisholm fire. Trapezoids representing the growth polygons were selected for input into the CALPUFF dispersion model (coordinates presented as UTM Zone 11).

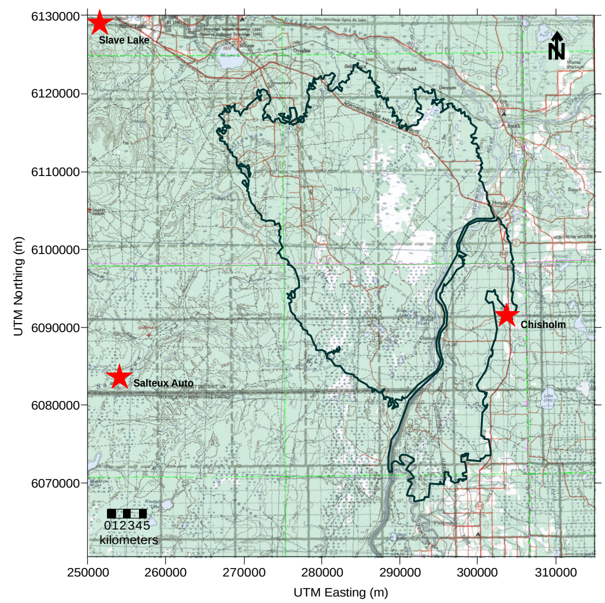


Figure 2. Map of the Chisholm fire area and nearby surface stations. The final extent of the fire is outlined in green. (coordinates presented as UTM Zone 12)

The Chisholm station was a portable station set up by AFP for measurement of meteorological variables near the fire. Ambient air quality data was available from Edmonton and Fort McMurray stations. The final extent of the fire and the three closest meteorological stations have been overlaid onto a topographical map (Figure 2).

The location of all the meteorological stations is given in Figure 4.

2.2.2 Lost Creek modelling domain

The airshed boundaries in this study are defined by UTM grid coordinates 630000 to 740000 meters east and 5470000 to 5675000 meters north (UTM Zone 11). The modelling domain selected encompassed an area of approximately 110 by 205 kilometers (2,255,000 ha). A 2 km grid resolution was used for the modelling domain. The domain extended from the fire location north to Calgary, the closest ambient air quality monitoring station.

Due to complicating factors including mountainous terrain, a less detailed analysis was carried out for the Lost Creek fire. Growth of the fire was not assessed. The Lost Creek fire was modelled for the time period of August 7th to August 17th, 2003, at a fixed size. This period was selected to represent the final extent of the fire. Significant fire growth did not occur over this period.

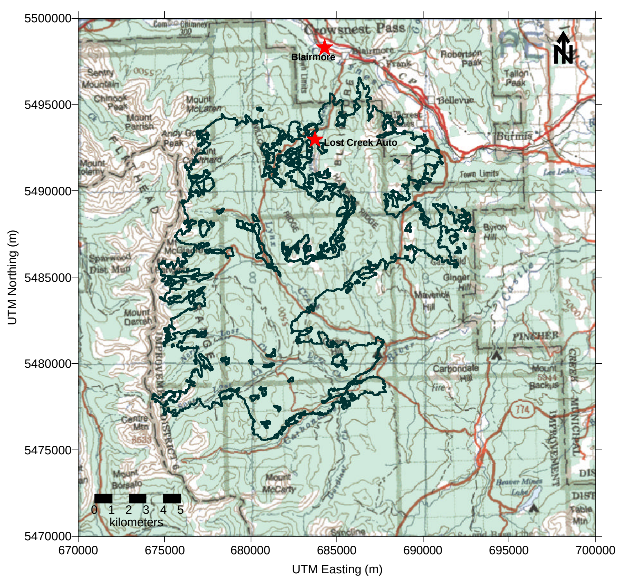


Figure 3. Map of the Lost Creek fire area and nearby surface stations. The final extent of the fire is outlined in green. (coordinates presented as UTM Zone 11)

Five metrological surface stations were selected for input into CALMET. The surface stations included Pincher Creek, Sparwood, Blairmore, Lost Creek and Calgary. Pincher Creek, Sparwood and Calgary are Environment Canada stations, while Lost Creek and Blairmore are automatic weather stations run by AFP. Ambient air quality data was available from Calgary. The final extent of the fire and the three closest meteorological stations have been overlaid onto a topographical map of the area (Figure 3). The extent of the modelling domain and all surface stations are presented on Figure 7.

2.3 *Evaluation of results*

Dispersion model results were compared with observed ambient air quality data and Moderate Resolution Imaging Spectroradiometer (MODIS) imagery data when available. Results presented here are based on $PM_{2.5}$ concentrations because $PM_{2.5}$ data was readily available from ambient monitoring stations. A combination of quantitative and qualitative analyses were used to derive conclusions and recommendations regarding the value of the process and results obtained.

3.0 RESULTS AND DISCUSSION

3.1 Chisholm Fire

The maximum 24-hour $PM_{2.5}$ plume for the Chisholm fire is displayed in Figure 4. The figure indicates that the plume did not reach north to Fort McMurray, so comparisons with monitoring stations in the Fort McMurray area have not been included. The location with the highest predicted concentration was Slave Lake.

In order to determine how the model performed compared with ambient air quality data, predicted and observed concentration results were tabulated and compared directly. Ambient air quality data used for comparison was available from two stations in Edmonton (Edmonton East and Edmonton Northwest). A time series of predicted and observed $PM_{2.5}$ concentrations is presented in Figure 5. For $PM_{2.5}$, the results show the model under-predicted concentrations when compared to the Edmonton stations for the periods that were influenced by the fire. If a diurnal variation on the emissions was applied, a significant increase in the predicted concentration would be expected and thus match more closely with ambient data. Although predicted concentrations are lower that the observed concentrations, they peaked at the same time.

The maximum concentration (275 $\mu g/m^3$) recorded at the Edmonton East station occurred on May 24th at 14:00. The shape of the predicted ground level concentration plume on May 24th at 14:00 is displayed in Figure 6. The maximum predicted concentration (118 $\mu g/m^3$) occurred on May 24th at 14:00, at the same time that observed concentrations peaked.

One explanation for the model under-prediction is the spatial differences in the modelled plume path compared to the actual plume. For example, it is possible that the highest concentrations at the time the maximum observed concentrations were predicted not actually in Edmonton, but nearby. To examine this possibility data near Edmonton (40 km northeast – in the direction of the main predicted plume at this time) was extracted from CALPUFF. Results show that the predicted concentrations were much closer to the ambient monitoring data indicating that due to the complexity of the surface wind fields, the model slightly under-predicted the plume trajectory towards Edmonton.

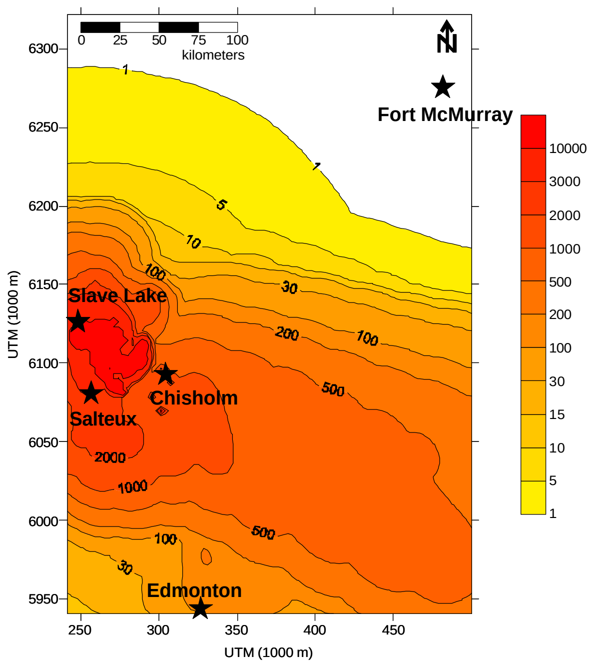


Figure 4. Maximum predicted 24-hour concentration for the Chisholm fire for May 24th to May 30th, 2001 (units µg/m^3). (coordinates presented as UTM Zone 12)

Results from the grid cell 40 km northeast of Edmonton predict a maximum 1-hour concentration of 183 µg/m^3 at 14:00 on May 24th. This is closer to the maximum of 275 µg/m^3 recorded at 14:00 on the same day at the Edmonton East station than the predicted model maximum from Edmonton of 118 µg/m^3.

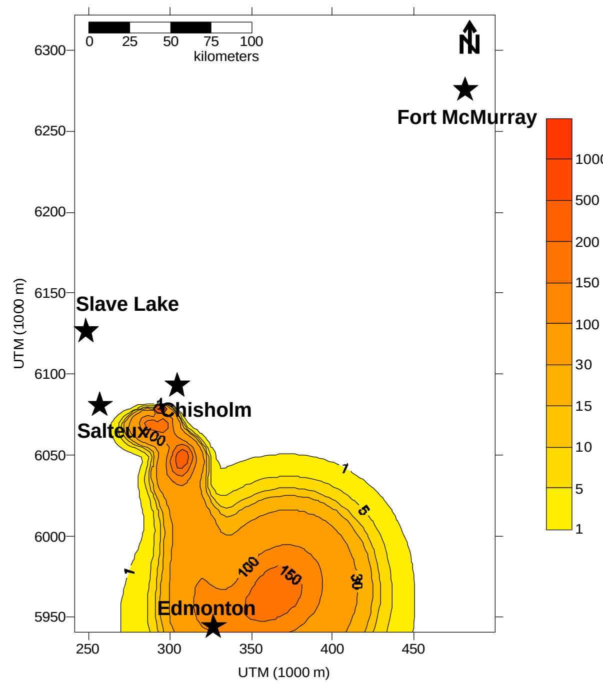


Figure 6. Spatial distribution of predicted 1-hour $PM_{2.5}$ concentrations on May 24th at 14:00 LDT (units µg/m^3). (coordinates presented as UTM Zone 12)

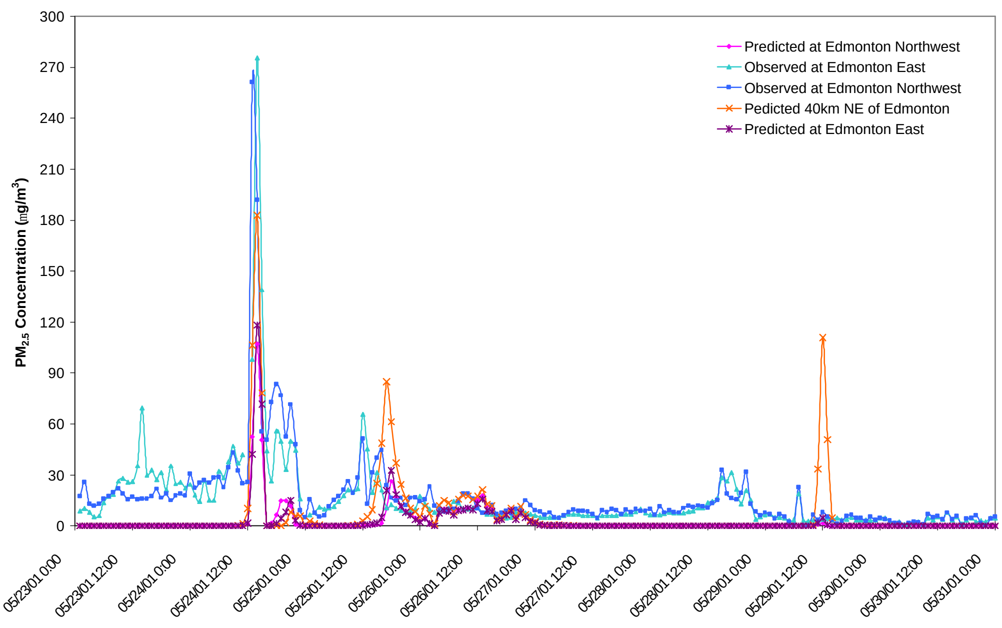


Figure 5. Time series of predicted and actual $PM_{2.5}$ concentrations in Edmonton from May 23rd to May 30th

3.2 Lost Creek fire

For this fire, the maximum concentrations at each of the meteorological surface stations were assessed. Out of the five stations, the highest concentrations were predicted at the Lost Creek station. As Lost Creek was actually consumed in the fire, it is not surprising that predictions are extremely high. Maximum 24-hour predicted concentrations exceeded the CWS 24-hour objective of 30 µg/m^3 at all stations, except Calgary. The maximum predicted $PM_{2.5}$ concentrations for the Lost Creek fire are displayed in Figure 7. The figure shows that the maximum concentrations in Calgary did not exceed the CWS objective for $PM_{2.5}$.

Due to other large fires burning in regions of British Columbia at the same time as the Lost Creek fire, the effect of the Lost Creek fire could not be isolated in the ambient air quality data measured in Calgary (north of the Lost Creek fire). Due to this limitation comparisons of predicted ground level concentrations with actual concentrations were not attainable. Instead comparisons of the modelled smoke plume to MODIS satellite imagery data were made.

Alberta Environment conducted ambient monitoring in the vicinity of Lost Creek using their mobile station on August 1st. Although not directly comparable to the model results, the magnitude of unpaired data can give an indication of how well the model performed. The monitor showed 1 minute averages ranging from approximately 60 to 900µg/m^3 from Pincher Creek through Bellman, Coleman and Hillcrest on Hwy 3. This is in the same general range that was predicted by the CALPUFF dispersion model.

3.3 Comparisons with Satellite imagery

Comparisons with MODIS satellite imagery are given in Figure 8 for the Chisholm fire. Results indicate there is good agreement between model predictions and actual observations. Modelling results for the Lost Creek fire are compared with satellite imagery in Figure 9. Other significant fires burning in BC at the same time of the Lost Creek fire can be seen on this figure. The comparison indicated good agreement of the predicted and observed plume for the Lost Creek fire, especially considering the complex terrain of the region. During the modelled period, The Lost Creek fire was being suppressed with significant resources, which may impact the applicability of the model.

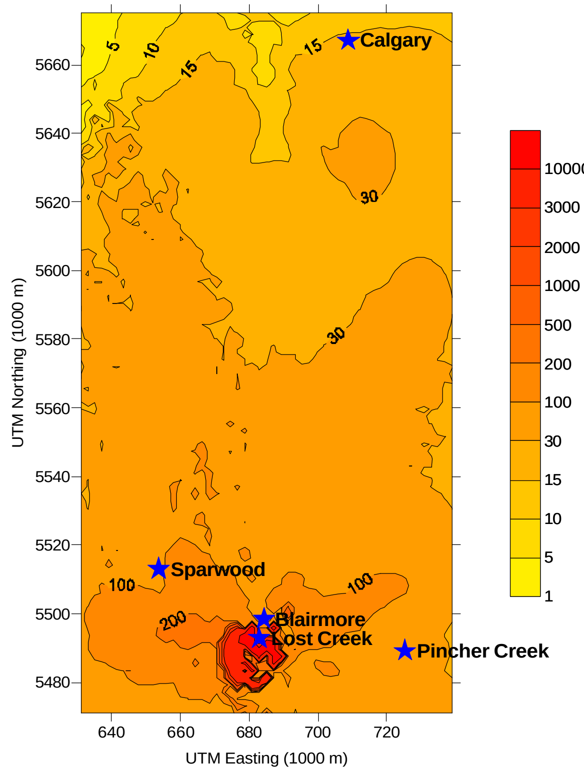


Figure 7. Maximum predicted 24-hour concentration for the Lost Creek fire for August 7th to August 17th, 2001(units µg/m^3).(coordinates presented as UTM Zone 11)

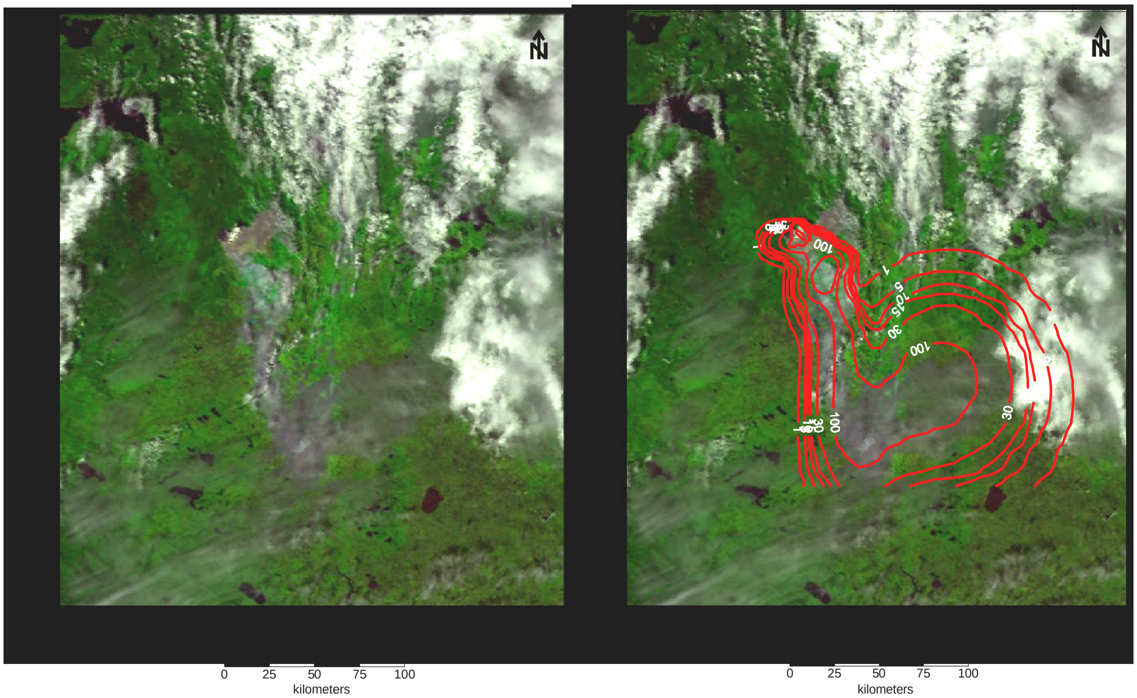
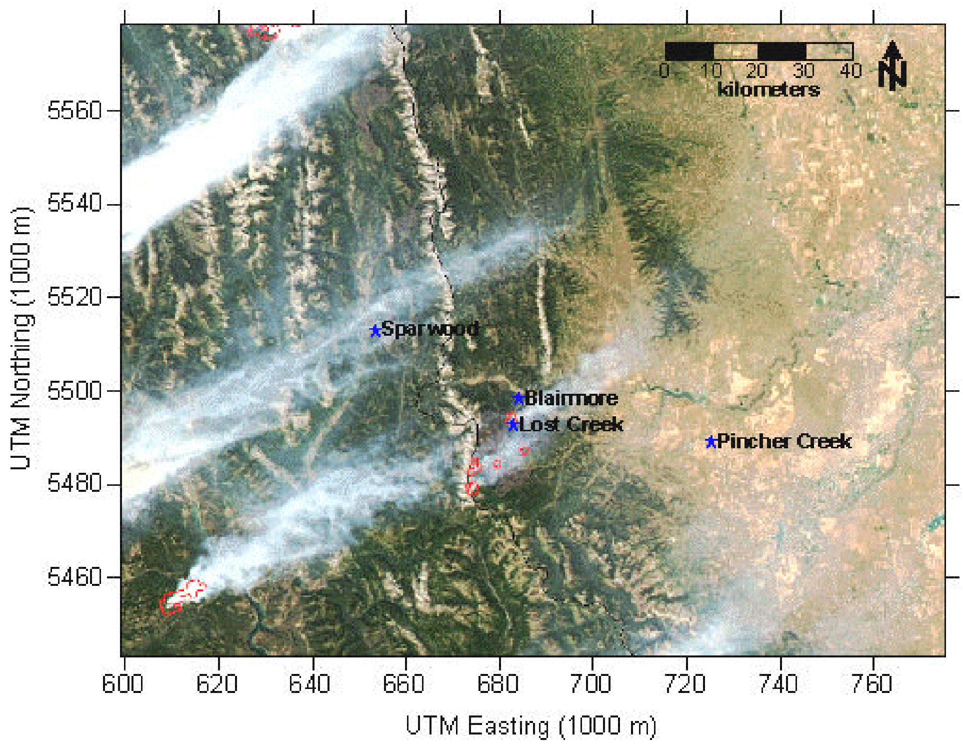


Figure 8. Plume comparison for the Chisholm fire. Satellite image was captured on May 24th at approximately 13:00. Smoke is dark grey in colour. Predicted ground level $PM_{2.5}$ contours are from results of CALPUFF modelling on May 24th at 13:00 (units µg/m^3). Contours are cut by the modelling domain boundary.



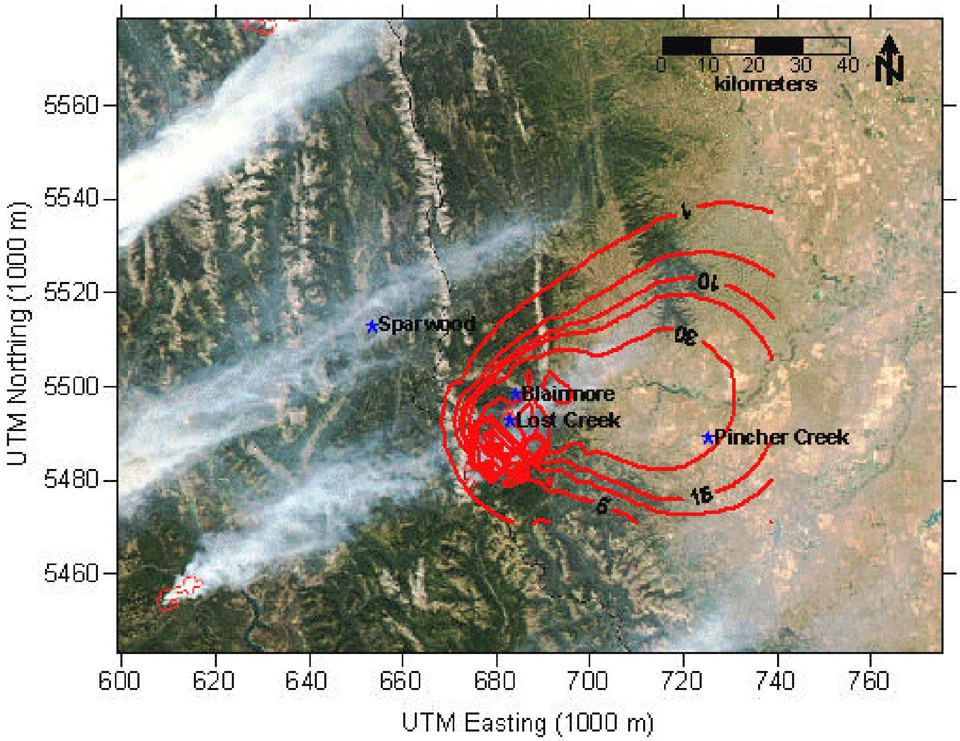


Figure 9. Satellite image of the Lost Creek fire and other fires burning in British Columbia. The image was captured on August 14th at 14:20 Mountain Standard Time (MST). . Overlaid predicted ground level $PM_{2.5}$ contours are from CALPUFF modelling on August 14th at 14:00 MST. Note: contours are cut at the modelling domain boundaries.

4.0 SUMMARY

The results indicated a good comparison between measured air quality data and predicted results for the Chisholm fire. Additionally satellite imagery data compares well. The Chisholm fire utilized surface station data that was located close to the fire, and in areas where observations were predicted, providing sufficient meteorological information to produce accurate wind speed and direction grids. A 100% weighting of the surface data was extrapolated to upper levels, with no shift in wind direction derived. In this case, the lack of prognostic initialization data, and upper air data being located far away from the fire, did not impact the results.

The Lost Creek fire required some reliance on upper air data to produce more realistic wind fields. In a complex terrain situation, knowledge of how winds may change with height is often difficult to derive, and modellers must have some knowledge of how the terrain is influencing the winds at the fire, and/or some prognostic initialization/forecast data, to gain confidence in the model output.

For the Lost Creek fire, predicted concentrations in Calgary did not compare well with measured ambient air quality data indicating that there may have been other sources of $PM_{2.5}$ during the same time period.. Nonetheless, the modelling indicates that the Lost Creek fire may have had a minor contribution to measured concentrations in Calgary. There is no way of knowing to what extent the Lost Creek fire did influence the concentrations. However, given that high concentrations were measured in Calgary, likely due to other fires in BC, it may be possible to model these fires, and conduct some back trajectory analysis to determine the influences to those maximums. The plumes from these other fires can be seen in satellite imagery data (Figure 9).

Overall, the Chisholm fire results appeared to perform well, indicating that (based on the data used), the methodology may be more applicable in flatter terrain areas, with a more homogeneous wind field. As Alberta is mostly flat, many more fires could be assessed using this type of methodology. If other ambient data could be used from other fires, further model tests could confirm the applicability. One advantage to the methodology, is that (once the standard model domain is set up), very little data is required to assess a prediction of plume transport and ground level concentrations. With some refinement, a person arriving on site, or with knowledge of a short term forecast, could enter the information into the CALMET file, and run an area source based on fire behaviour predictions, thus acquiring predicted concentrations for various locations, providing the information necessary to make health risk decisions accordingly.

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