The Canadian Smoke Newsletter

Spring/Summer 2010

"Connecting diverse terrestrial, emissions, air quality and modelling communities."

Welcome to the 2010 Spring-Summer issue of The Canadian Smoke Newsletter. Please note that the Newsletter is published twice per year and that from this point on, issues will be labelled as Spring/Summer and Fall/Winter.

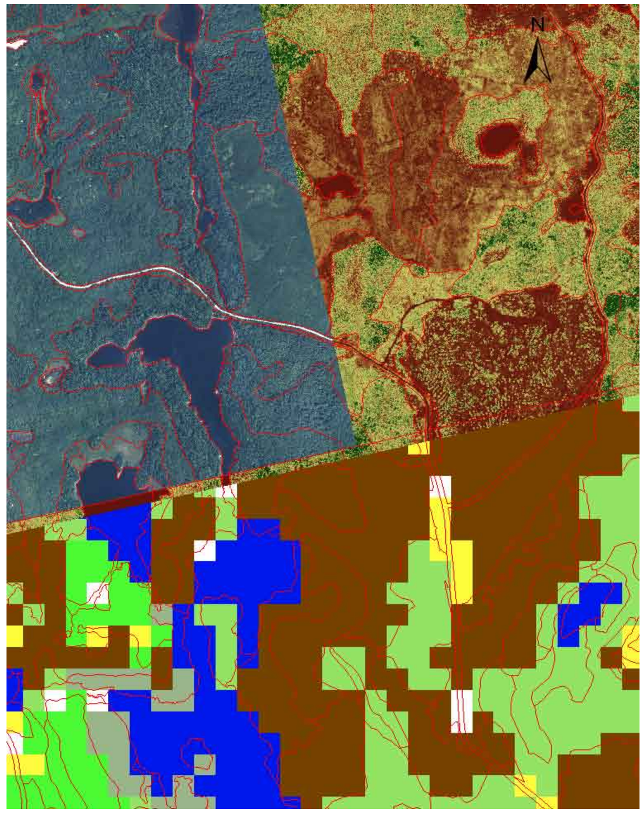
Of continuing interest to the smoke prediction community in Canada is the progress of the BlueSky Western Canada extension. The project came to a standstill in early 2009 due to severe funding limitations. Fortunately through partnered contributions by the British Columbia Ministry of Environment and Environment Canada, the final parts of the system were tied together. Under the leadership of Steve Sakiyama at the BC Department of Healthy Living and Sport, the BlueSky team together with staff at the University of British Columbia under Roland Stull as well as Sonoma Technologies Inc. have succeeded in setting up a Canadian version of BlueSky. The system has undergone test runs using selected fires from the BC interior in 2009. We will have an in-depth look at this project in the upcoming Fall/Winter 2010 issue.

The Fall (now Fall-Winter) issues of the CSN have usually filled this column with a listing of upcoming conferences around the world which are of interest to the smoke community. Since few of us have the wherewithal to attend each conference, I invite those of you who do attend to send a short email (to al.pankratzATec.gc.ca) outlining the salient aspects of the conferences from the smoke point of view. Point form is fine. I will compile the results and add them to the next issue of the CSN. In this way, community input will assist those who are considering attending that particular conference in the future, and provide potentially valuable information for people who were unable to attend.

Cheers,

Al Pankratz

Disclaimer: This informal newsletter is produced by the Air Quality section of Prairie and Northern region of Environment Canada on behalf of the smoke community. It does not represent the policies of Environment Canada.



Composite image of remote sensing data: Air photo, LiDAR canopy height model data and FRI polygons courtesy of Chad St. Amand, Tembec. Fuel type map generated from Earth Observation for Sustainable Development of Forests (EOSD) land cover map of the forested area of Canada.

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Conference Notes: AWMA ACE 2010 Smoke Sessions

The Air and Waste Management Association's 103rd Annual Conference and Exhibition took place in Calgary June 22-25. Most sessions were devoted to topics of peripheral interest to the smoke community, but there were several sessions relevant to readers of this newsletter. Summaries are provided in no particular order.

Brian Stocks of B.J. Stocks Wildfire Investigations Ltd. delivered a talk at the AWMA Young Professionals session on visibility and PM2.5. This session was designed to give individuals in other areas of air quality research or who were in the early stages of their careers an overview of issues pertaining to vegetation fire smoke (VFS). The talk focused on the global nature of fire, and increasing impacts in various areas such as climate change and human health. It noted that VFS can contain toxic compounds, respiratory irritants, carcinogens and asphyxiates and that both public and fire fighter exposure limits are being investigated. Also highlighted was the fact that wildfires reactivate deposited compounds such as mercury and radionucleids. Increasing scientific interest in the problem of wildfire smoke was mentioned, as was the need for more support for prediction and modelling. Societal issues such expanding population, smoke in urban areas and increased human activities in formerly untouched natural areas were deemed to be of increasing importance in the future as expected climate changes alter historic patterns of wildfire (Figure 1).

The Western Regional Air Partnership (WRAP) is a partnership of local, tribal, state and federal air agencies concerned with regional air quality in the western United States. WRAP has

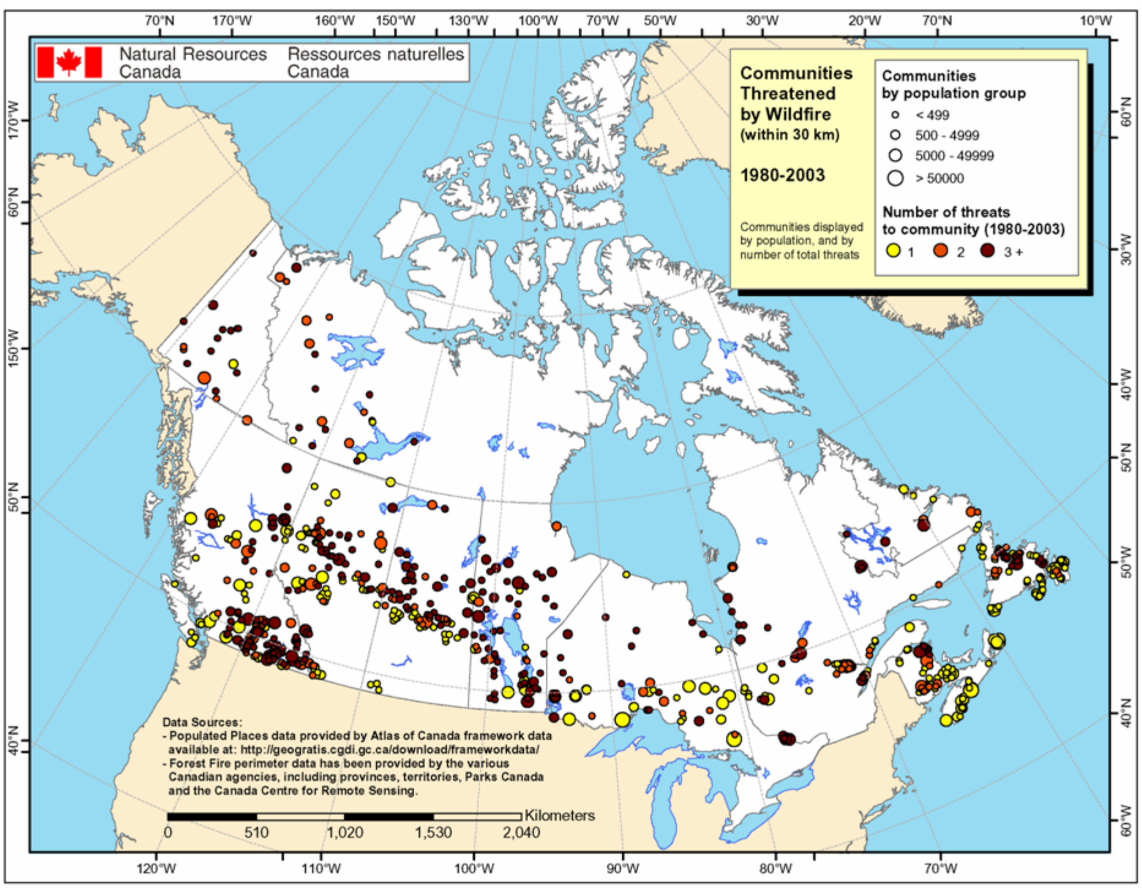

Figure 1. Natural Resources Canada depiction of communities threatened by wildfire in Canada from 1980-2003.

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set up the Fire Emissions Tracking System or FETS at http://wrapfets.org. This is a web-enabled database of fire activity which is used for planning and analysis purposes. The presenter, Tom Moore, indicated that wildfire emissions inventories need to be updated yearly due to increasing requirements for the latest information. FETS also provides support for air quality modelling, greenhouse gas and carbon reporting as well as assessment of short-range climate forcers.

Funded by the US Joint Fire Science Program, SEMIP is an ambitious idea. SEMIP, short for the Smoke and Emissions Model Intercomparison Project, is a community project that investigates the network of current fire and smoke models. It seeks to standardize evaluation of different models in each step of the chain from wildfire to smoke dispersion modelling. Using test cases which are linked through the BlueSky framework, the behaviour of the models in different circumstances is characterized, and statistics on performance and ranges of uncertainties derived. Questions to be answered include: does increased accuracy in model inputs make any difference to uncertainty ranges? How is uncertainty important for regional assessments? How is uncertainty relevant to air quality predictions? The presentation by Sim Larkin noted that many fire emission inventories exist, but differ substantially. Variations in burn areas, fuel loadings, fire detects by various satellites, fuel consumption and plume rise models all contribute to substantially different results when linked together in different combinations. In order to assist in the evaluation process, the Smartfire2 system is being developed which will attempt to reconcile multiple inputs and multiple processing paths with the aid of a "trust" metric for each input stream. More information is available at http://semip.org.

Information transmitted by the MODIS sensors on the Aqua and Terra satellites are the backbone of many fire and smoke research programs. It is therefore to be expected that the lifetimes of the two satellites will be of particular interest to users. It appears that fuel on board the satellites will run out somewhere around 2016 for Terra and 2018 for Aqua. While the NPOESS satellite is expected to make up some of the lost data, its instruments will not have the spectral resolution of the two MODIS instruments. A comment was made at one of the presentations that the smoke research community is now in the heyday of research data and will need to anticipate a reduction in the amount of information available to it over the next few years. §

Report by Al Pankratz

Thinking of contributing to the Canadian Smoke Newsletter?

We are interested in articles from across the globe, not just in Canada. To contribute, or to be added to/removed from the email list for the CSN, send a note to al.pankratzATec.gc.ca.

- **Please submit any articles as a .txt, Word or OpenOffice file. Format text as 11 point Times New Roman, linespacing single.**
- **The article can be short (minimum 400 words) or long (up to 5000 words).**
- **Please include images and diagrams if possible. These serve to illustrate your article and allow flexibility in layout.**
- **Ensure that you have permission to use any graphics you include and credit the artist/photographer if necessary.**
- **Images/diagrams embedded in your documents should have sufficiently high resolution to allow reasonable resizing without degradation.**
- **Include captions for any photos, figures or tables.**
- **Include your name, title and institutional affiliation. If you are open to being contacted by readers, please add your mailing address and/or email address.**
- **You may submit your article in English or French. Please note that we are not able to have documents translated from French to English at this time.**
- **Your submissions may be edited for space, spelling, grammar, etc.**
- **Where possible, you will be provided with a final draft before the newsletter is published in order to ensure that accuracy and the sense of the article has been maintained.**
- **Depending on space constraints, we may retain some articles for publication in succeeding issues.**
- **Please ensure that acronyms and potentially obscure references are adequately explained on first use.**
- **The target audience is composed of professionals in government, industry and academia, all of whom are involved with smoke and smoke issues. Both descriptive and technical articles are welcome.**
- **The Canadian Smoke Newsletter will be published via email and on the Internet. Contents of all articles will be freely shared with anyone who is interested.**

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Fuel-type mapping for the CWFIS: Past, Present, and Future

by Brian Simpson, Peter Englefield, and Kerry Anderson
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Wildland fire is a frequent event in Canada's forests. Each year, approximately 7,000 forest fires burn over 1.7 million hectares [Natural Resources Canada, 2009]. Fire is a natural part of the landscape and has helped to maintain forest health and diversity for the past 10,000 years. On the other hand, these fires destroy valuable timber, disrupt forest-based communities and affect public health and safety. Understanding forest fires and fire behaviour is important in mitigating their effect on the Canadian landscape.

Countryman [1966] describes the fire environment as the conditions, influences, and modifying factors that control fire behaviour. The fire environment consists of three principal components: fuel, topography, and weather. Fuel represents any organic material – living or dead – that is available for combustion and thus is the driving force behind fire behaviour. Topography represents elevation characteristics of a landscape, such as slope and aspect, that can influence fire spread. Weather represents the atmospheric elements that directly affect combustion, such as wind and rain. Together, these three factors make up what is referred to as the fire environment triangle.

Of the three major components affecting fire spread, forest fuels represent the most spatially diverse and dynamic predictor of the three. Differences within fuels such as the height of the forest canopy above ground or whether deciduous trees have leafed out can lead to variations in propagation rates of ten to a hundredfold. Mapping forest fuels is crucial to predicting potential fire growth on the landscape. With respect to smoke modelling, fuel characteristics have a significant impact by influencing fire behaviour and therefore the fuel consumption rate which in turn affects the amount of smoke emitted to the atmosphere. Other fuel characteristics can affect smoke chemistry, which may have an impact on health and safety. This paper summarizes efforts to map forest fuels and include them in fire management systems.

Canadian Forest Fire Danger Rating System

The Canadian Forest Fire Danger Rating System (CFFDRS) is a model developed by the Canadian Forest Service over the past 40 years to predict the potential impact of fire on the landscape [Stocks et al., 1989]. The CFFDRS consists of two principal sub-systems: the Canadian Forest Fire Weather Index (FWI) System and the Canadian Forest Fire Behaviour Prediction (FBP) System. The FWI is used to assess the impact of weather conditions on fuel moisture and fire behaviour [Van Wagner, 1987]. The FBP system provides quantitative estimates of potential head fire spread rate, fuel consumption, and fire intensity, as well as fire descriptions [Forestry Canada Fire Danger Group, 1992]. With the aid of an elliptical fire growth model, the FWI and FBP systems together give estimates of fire area, perimeter, perimeter growth rate, and flank and back fire behaviour. Required input data include weather, topography, and fuels.

16 fuel types in the FBP system

1. C1 – Spruce-lichen woodland
2. C2 – Boreal spruce
3. C3 – Mature jack or lodgepole pine
4. C4 – Immature jack or lodgepole pine
5. C5 – Red and white pine
6. C6 – Conifer plantation
7. C7 – Ponderosa pine or Douglas fir
8. M1 – Boreal mixedwood - leafless
9. M2 – Boreal mixedwood - green
10. M3 – Dead balsam fir/mixedwood - leafless
11. M4 – Dead balsam fir/mixedwood - green
12. S1 – Jack or lodgepole pine slash
13. S2 – White spruce/balsam slash
14. S3 – Coastal cedar/hemlock/Douglas-fir slash
15. D1 – Leafless aspen
16. O1 – Matted (O1a) or Standing (O1b) grass

Canadian Wildland Fire Information System

The Canadian Wildland Fire Information System (CWFIS) is a computer-based fire management information system that monitors fire danger conditions across Canada (http://cwfis.cfs.nrcan.gc.ca/). Daily weather conditions and satellite hotspot data are collected from across Canada and used to generate fire weather, fire behaviour and fire occurrence maps in near real time.

The CWFIS has produced national maps of fuel types since 1995. Fuel type maps were developed for use in geographic information systems starting in the 1990s in order to produce maps of FBP outputs. Many of the provincial and territorial fire management agencies have also produced fuel type maps based on forest inventory data. Recently, remote sensing has been used more extensively.

The first fuel type map (Figure 1) used by the CWFIS was a reclassification of land cover based on Advanced Very High Resolution Radiometer (AVHRR) imagery [Palko et al., 1993]. Although the fuel type classification was done in 1995, the imagery was acquired during the summers of 1988 to 1991. Of the 16 FBP fuel types, only five were used in the map.

Classification was basic. Coniferous forest land was classified as C2, "transitional" forest land as C1, hardwoods as D1, all mixedwoods as M1, and cropland or grassland as O1. Because there was no way to distinguish tree species or stand age with coarse remotely sensed data, other coniferous or mixedwood fuel types could not be identified. For example, mature jack pine (C3) and immature jack pine (C4) could not be distinguished from boreal spruce (C2).

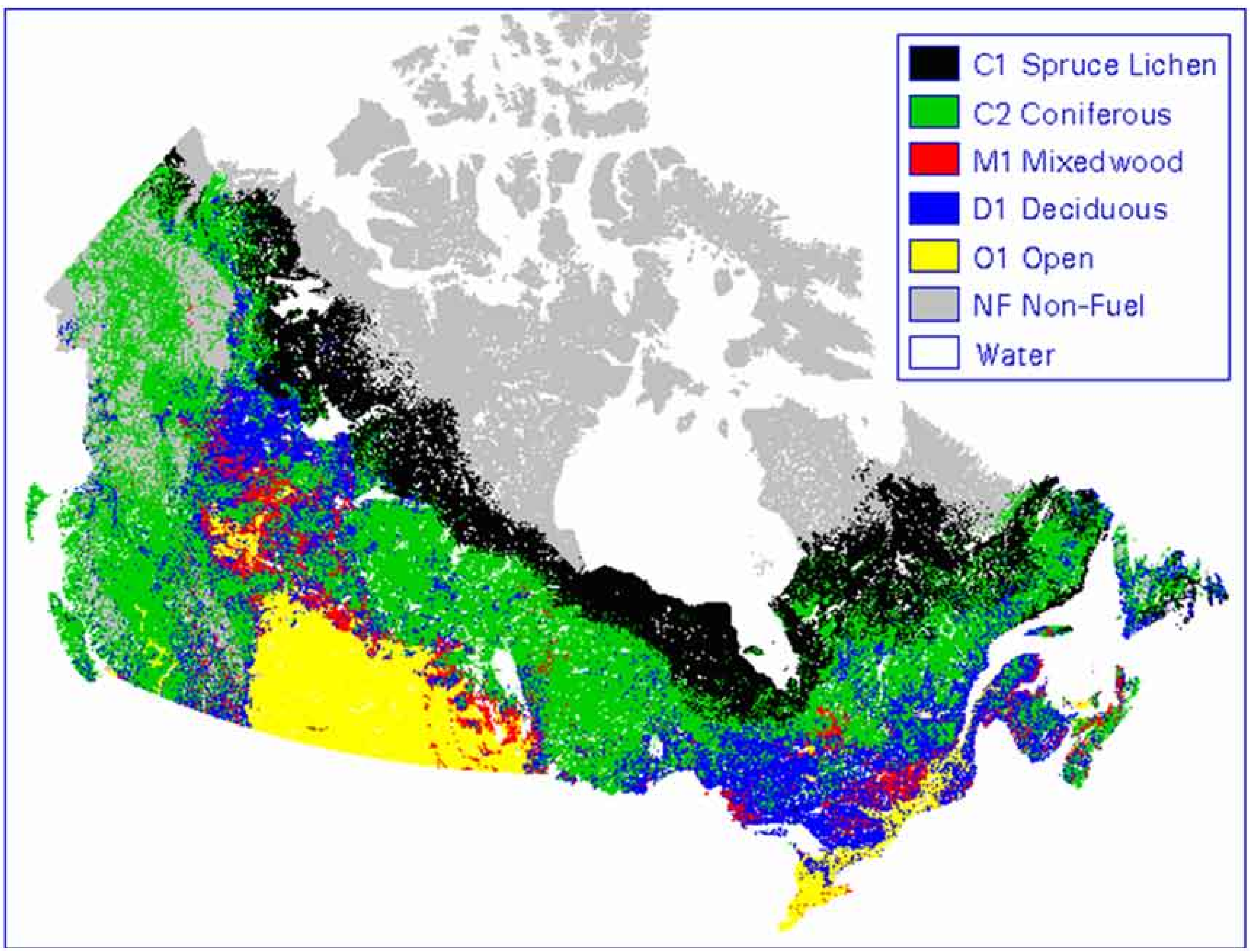

Figure 1. Original FBP fuel type map of Canada based on Cihlar and Beaubien (1998).

The second fuel-type map used by the CWFIS was also a reclassification of AVHRR-based land cover [Cihlar and Beaubien, 1998]. The imagery was acquired from one of the Polar Operational Environmental Satellites operated by the National Oceanic and Atmospheric Administration (NOAA), called NOAA-14, during April to October 1995. The CWFIS began to use this map in 2000.

The land cover map was produced by the Canada Centre for Remote Sensing (CCRS), a sector within Natural Resources Canada [1999]. This land cover map contained more detailed information about stand density, which was used to distinguish C1 from C2. Shrublands were classified as deciduous (D1) and mixedwood (M) classes were distinguished by the percentage of coniferous trees they contained. Cropland and grassland were classified as O1 (Figure. 2).

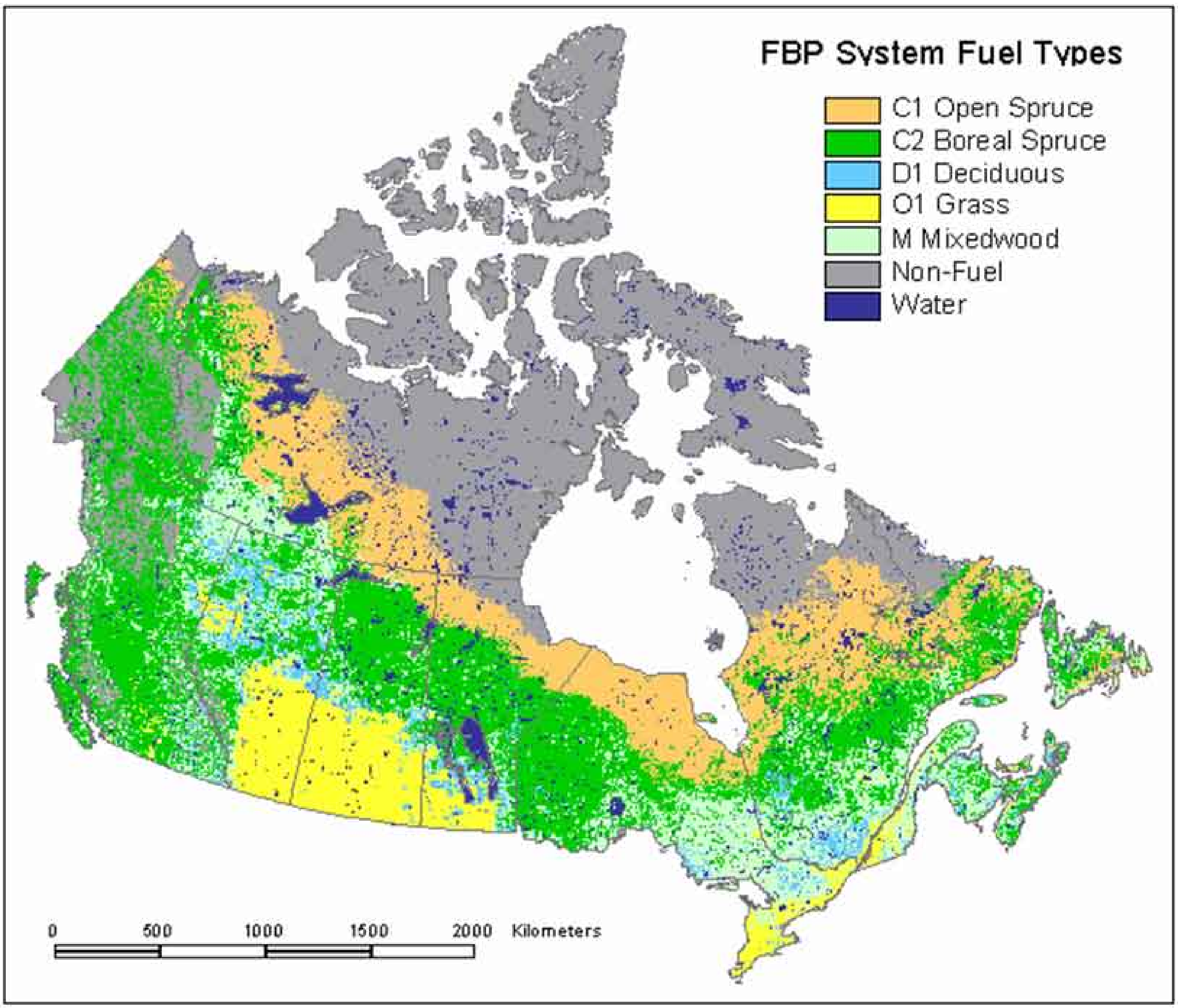

Figure 2. Updated FBP fuel type map of Canada based on reclassification of AVHRR land cover data.

A third fuel type map began to be used by the CWFIS in 2005 [Nadeau et al., 2005], in which multiple sources of data were used to determine fuel types. Vegetation types were determined using a land cover map based on 2000 Satellite Pour l'Observation de la Terre (SPOT) VGT imagery [Latifovic et al., 2004]. Additional information was obtained from Canada's Forest Inventory (CanFI) 2001 [Natural Resources Canada, 2004a and 2004b]. In addition, the Terrestrial Ecozones of Canada [Ecological Stratification Working Group, 1996] were used as a guide for a reclassification scheme for each ecozone on the basis of local knowledge and expert opinion.

Because CanFI data includes species information, it was possible to separate spruce (C1 and C2) from pine (C3, C4, C5, and C7). In some cases, it was possible to use CanFI to separate mature jack or lodgepole pine (C3) from immature jack or lodgepole pine (C4). Where this was not possible, the fuel type was designated as C3/4 (Figure 3). Also, for the first time, cropland and tundra were distinguished from grassland. For FBP calculations, the CWFIS considers cropland as O1 with low curing, and tundra as O1 with a low fuel load. The number of fuel types mapped has increased significantly from five to nine.

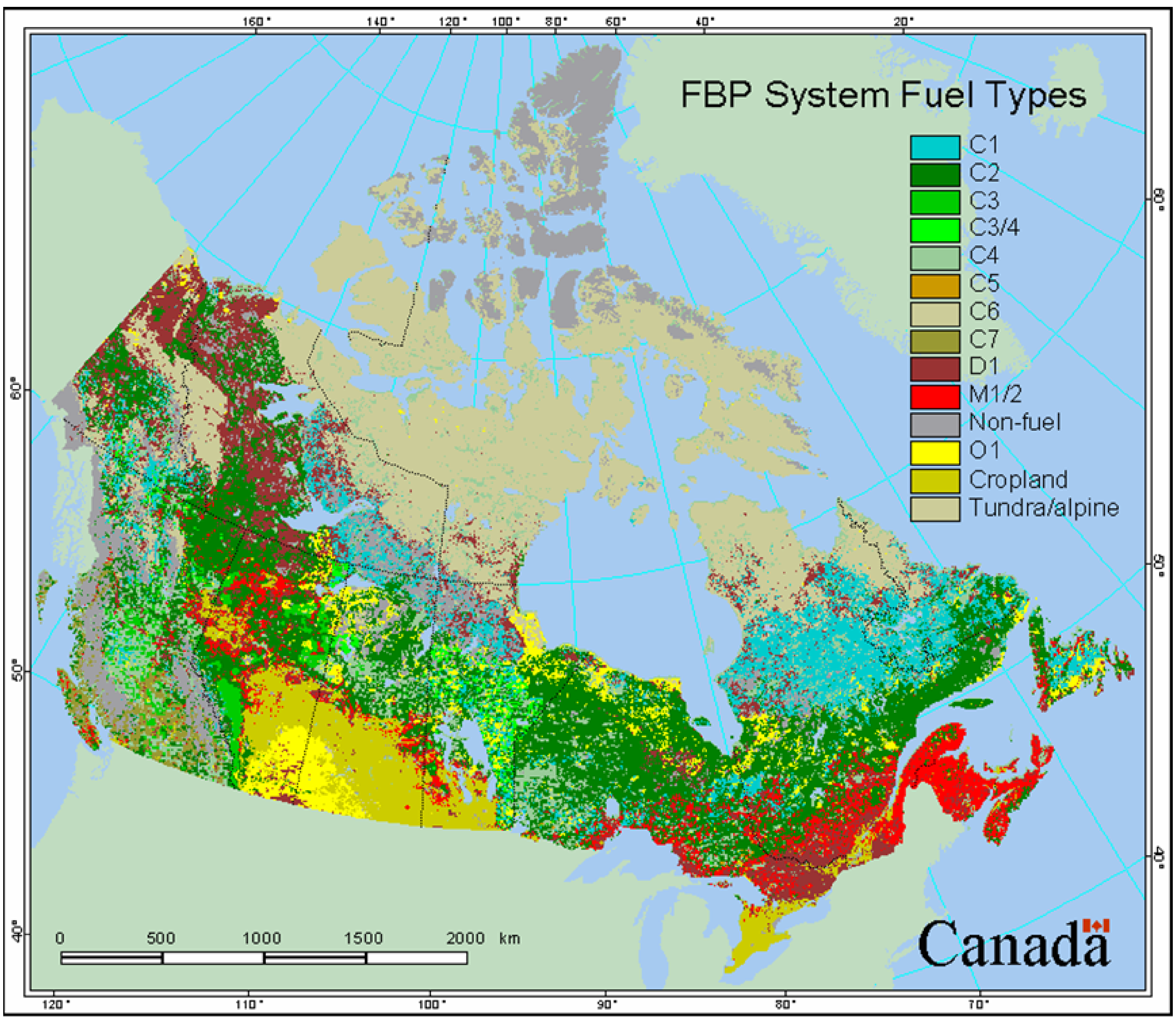

Figure 3. Third fuel type map of Canada produced with land cover and forest inventory maps using fuzzy logic.

The Future

Although FBP fuel types have been and will continue to be widely used in Canada, future versions of the map will include a database of species and structural characteristics for each raster cell. Land cover data is more widely available now than in the past because of the development of new remote sensing technologies.

Despite the advances shown by successive progressive fuel type maps, there are several areas that can be improved upon. They are species assignment, resolution, and age of imagery.

Species assignment. The Canadian FBP system relies on a limited number of fuel types that – for mapping purposes – were primarily defined by species. However, the assignment of species to a fuel type was a substitute for some measure of structure. For example, a stand that has the characteristics of a C2 – Boreal Spruce stand might be assigned to that fuel type even if it were a different species, such as eastern larch. This is particularly true for those species (such as larch) that are not represented by an existing fuel type. Therefore it is very important to know not only the species, but also the structure of the stand. However, satellite land cover maps may not provide either.

Resolution. All three historical fuel type maps are rasters limited to a resolution of 1 km^2. Future fuel type maps will use additional data to increase the resolution to 250 x 250 m, resulting in a 16-fold increase in the number of grid cells. Although higher resolution satellite products do exist, the number of freely available supplementary data sources that are high resolution, up to date and that cover all of Canada's forests are limited. In the future, new landcover maps may allow for even higher resolution fuel maps for Canada's forests should there be a need at the national scale for detailed fire growth modelling.

Age of imagery. A persistent problem with the production of national fuel type maps has been the age of the images used to generate the products. It takes time to acquire national cloud-free coverage from the various satellite sources, and still more time to use that data to generate a land cover map. Once the land cover map is available, it must then be converted to a fuel type map using other data sources to provide, for example, species information. The sources of species data have often been much older than the land cover map itself. Therefore, recent events like clearcuts, insect infestations, blowdown events and even wild fires might not be reflected in the fuel type map. Additionally, it is important that future disturbances – such as harvesting or wild fires – that affect fuels are recorded and accounted for in the fuels map. To date, CWFIS fuels maps have not been updated to reflect landscape level disturbances. Ideally, any future system will incorporate a mechanism to update the fuel type on an annual basis.

Many types of disturbances are currently mapped across Canada, on an ongoing basis. Fires are mapped in the National Burned Area Composite (NBAC). Deforestation is tracked with a sampling protocol by the Deforestation Monitoring Group and updated annually for the National Inventory Report [Environment Canada, 2010]. Additionally, efforts are under way to produce a Canadian Forest Service nationwide insect outbreak atlas. Combined with national carbon accounting procedures [Kurz et al., 2009], they also offer a potential mechanism to refine estimates of fuel loads.

With currently available land cover products such as the MODIS land cover map produced by the Canada Centre for Remote Sensing [2008], it should be possible to achieve the desired levels of resolution and detection of changes to land cover. However, identification of tree species continues to be an issue when using satellite imagery. Additional sources of information are required to assign an FBP fuel type to each pixel.

Where they are available, provincial fuel type maps would be an ideal source for fuel type classification. Additional stand characteristics can be derived from supplementary sources such as standard polygonal forest inventory maps. For example, species, merchantable and total volume, basal area, height, and crown closure might all be available.

One area of particular interest is airborne LiDAR data; although current operational implementation of airborne LiDAR is limited in Canada it is becoming increasingly widespread and cost effective. One such study in Ontario [Woods et al., 2008] demonstrated that the stand characteristics described above can be directly measured or inferred with LiDAR data at landscape scales. Other information that might be available from LiDAR data includes vertical structure (e.g., number of stems by height class) and horizontal structure (e.g., gaps in the forest canopy).

As more data becomes available, additional products and tools will be able to make use of the fuel type map. Fuel consumption models such as CANFIRE [de Groot 2009] use parameters and fuel load values such as those described above. Information on stand structure could be used to model fuel treatments or fire behaviour in ways that are difficult with currently available data. In a static fuel type map, current FBP fuel types are difficult to apply in some situations such as successional changes following insect damage to a forest.

As these new tools become available, an improved fuels map will be produced for Canada. While past iterations were static, the future product should be dynamic, changing as new data becomes available. Finally, the new fuels map will include other information that will be of use to modellers and fire behaviour specialists in addition to just FBP fuel type. §

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Impact of the 2003 Forest Fires on Air Quality in Western Canada

by David Lavoué,
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Fifty percent of Canada's land area is covered by forest of which the boreal forest represents 80%. On average, 6000 fires burn each year (based on records for the past 25 years), and in the process consume 2 million hectares (ha). Wildfires in the boreal forest affect forest resources, vegetation patterns, and carbon cycling. In the central and western provinces as well as the western territories, numerous poor air quality episodes are caused by smoke events. Wotton and Stocks [2006] state that, on average, 5000 people are evacuated every year due to smoke and fire hazards. Over the years, various North American research groups have monitored and analyzed the episodic nature of wildfire smoke and its impact on air quality across the continent (e.g., Wotawa and Trainer [2000]).

Wildland fires represent a large fraction of total PM emissions in Canada [Lavoué et al., 2007; Lavoué and Stocks, 2010] and are considered by many as the "unmanageable" portion, unlike anthropogenic combustion processes. The 2003 fire season in British Columbia accounted for about 75%, 60%, and 45% of the annual PM2.5, black carbon, and carbon monoxide emissions respectively for that province.

In the summer of 2003, air quality monitoring stations located in the British Columbia Interior recorded high levels of PM2.5 for several weeks (Figure 1a). The Canada Wide Standards (CWS) PM2.5 limit of 30 µg/m^3 was exceeded numerous times in August and early September at Golden, Kamloops, Kelowna, and Vernon. In particular, high concentrations were recorded on August 8th and August 21st at Kamloops and Kelowna, respectively.

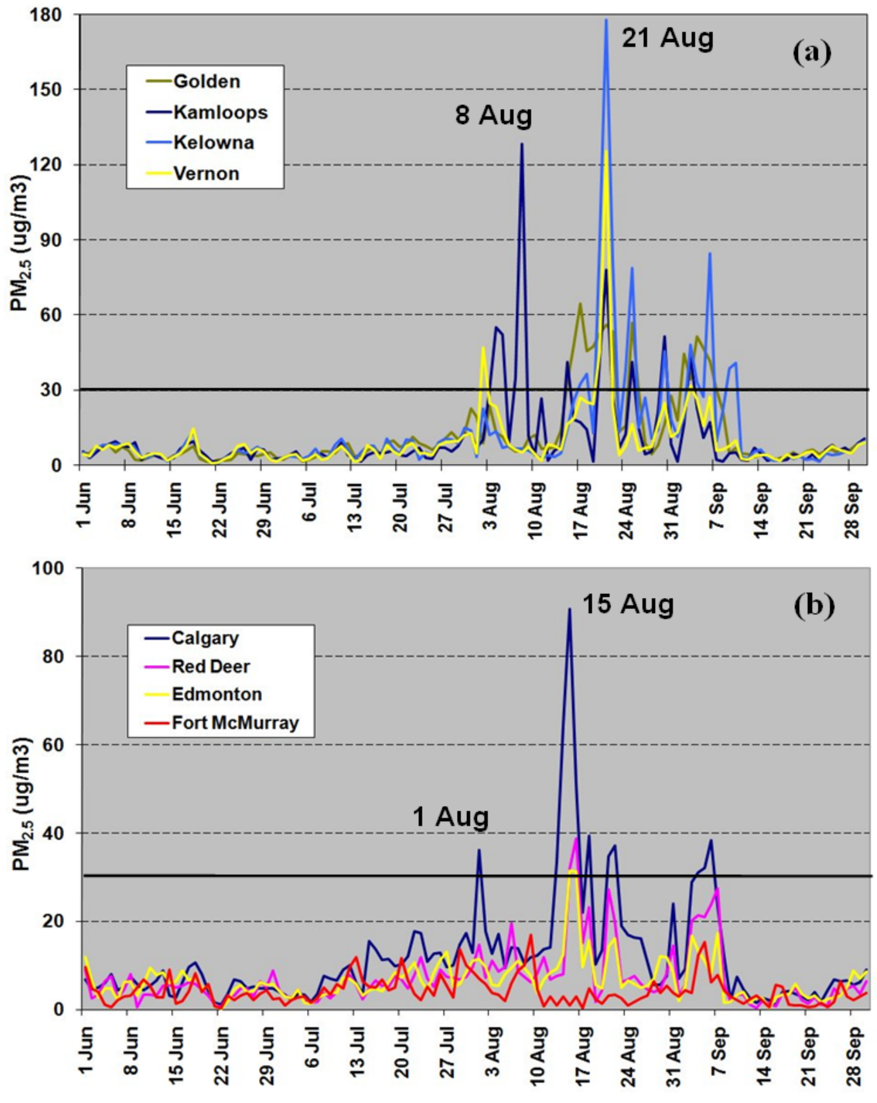

Figure 1. Daily averaged PM2.5 concentrations at several sites across (a) British Columbia Interior and (b) Alberta, from June through September 2003. Straight black lines indicate the CWS daily limit of 30 µg/m^3 for PM2.5.

MODIS satellite imagery shows smoke plumes on August 14th (Figure 2a) and smoke filling the valleys of the B.C. Interior on August 20th (Figure 2b). Health impacts of these smoke plumes were described by Henderson and Brauer [2008] in a previous issue of the Canadian Smoke Newsletter. Locations and final sizes of wildfires were obtained from the British Columbia Ministry of Forests and Range, and Parks Canada. Fires burning on August 14th and 20th were superimposed on the satellite imagery, using MapInfo Professional.

Southwesterly winds pushed the smoke plumes into populated areas of southern Alberta. PM2.5 levels increased significantly in Calgary, Red Deer, and Edmonton but not to the magnitude experienced in the British Columbia Interior (Figure 1b). Nevertheless, very poor air quality was observed in Calgary for several days, particularly on August 15th. Northern Alberta appeared to escape the bulk of the smoke, with the town of Fort McMurray (400 km northeast of Edmonton) registering no increased values. Overall, the summertime smoke affected approximately one third of the population of Alberta. Remote sensing on August 14th clearly shows the elongated shape of the plumes en route to the Calgary area.

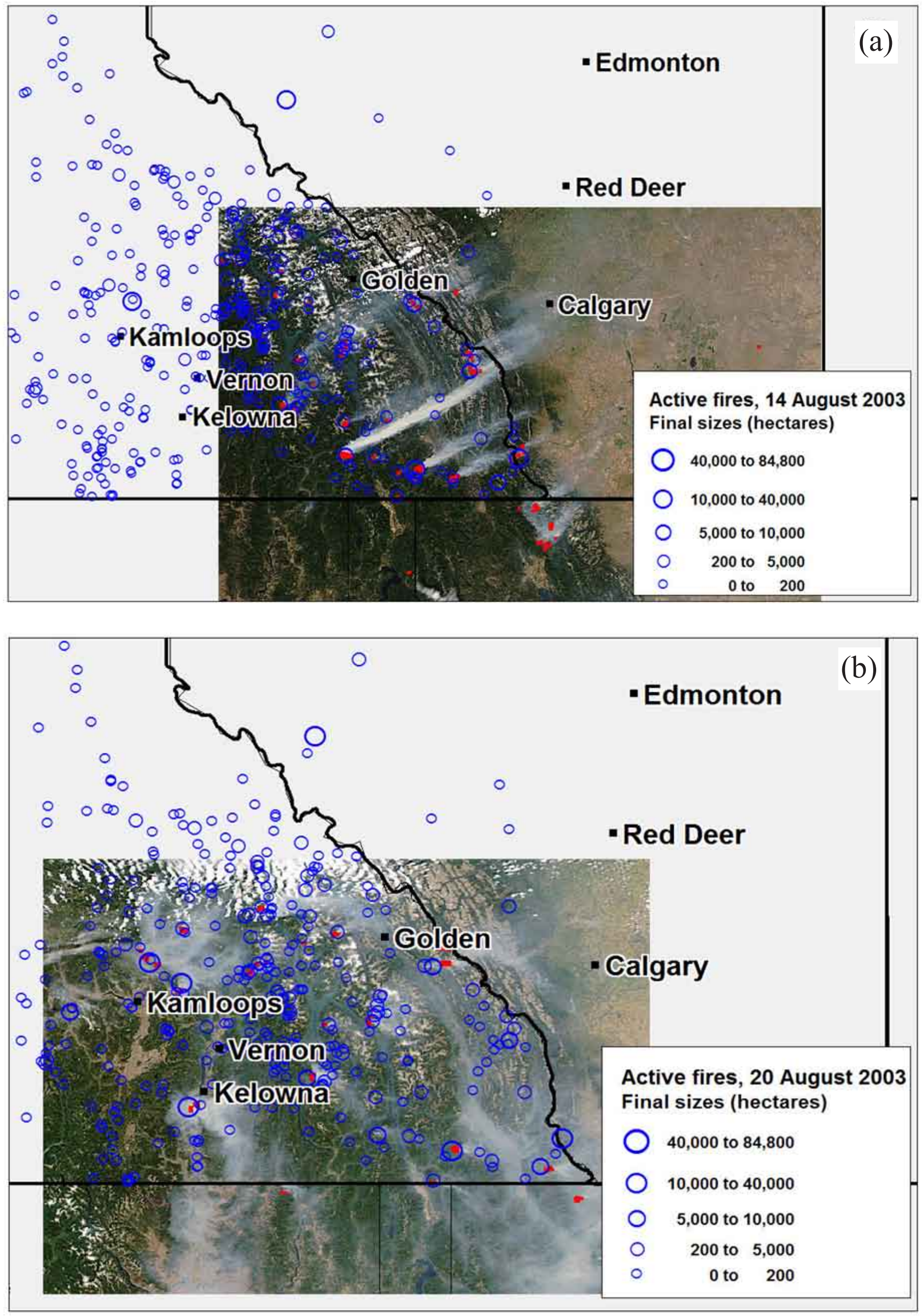

Figure 2: MODIS imagery for western Canada on (a) 14 August 2003 and (b) 20 August 2003 (courtesy of the MODIS Rapid Response Team, NASA Goddard Space Flight Center). Active fire locations provided by the B.C. Ministry of Forests and Range, and Parks Canada.

Several simulations of the 2003 smoke plumes were run using the FLEXPART model. FLEXPART is a Lagrangian particle dispersion model originally developed by Andreas Stohl, now at the Norwegian Institute for Air Research [Stohl et al., 1998; Stohl et al., 2005]. Research groups all over the world have used the model for atmospheric studies. For this study, Andreas Stohl ran FLEXPART using black carbon emission point sources [Lavoué and Stocks, 2010] and ECMWF meteorological fields for western Canada. The primary goal

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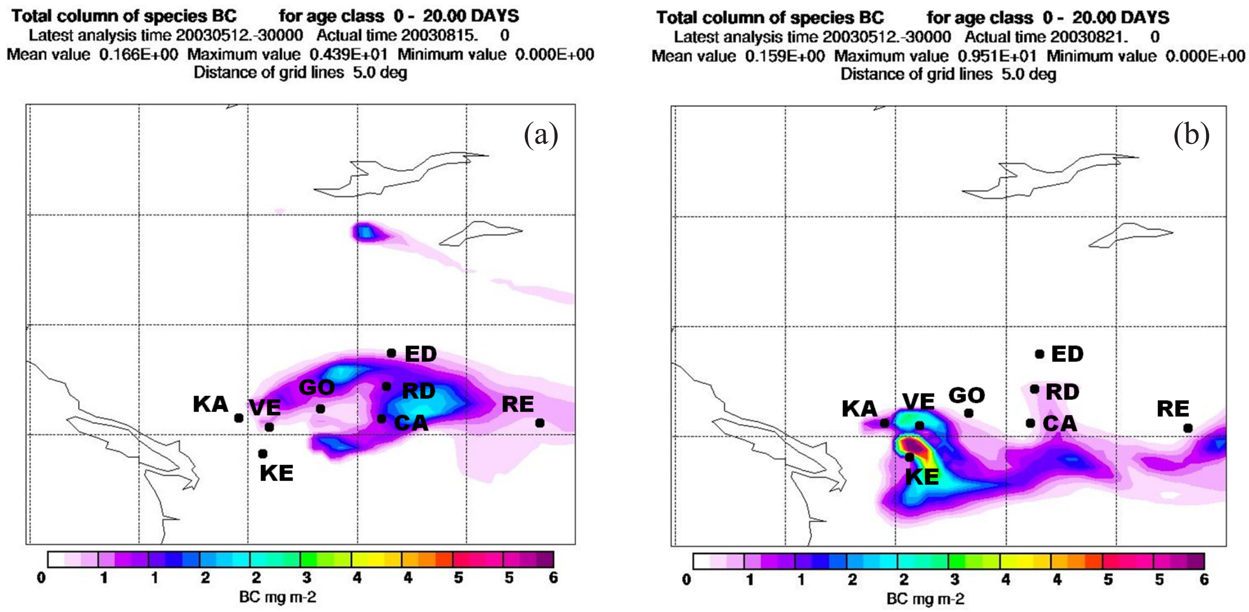

Figure 3. Column loading of black carbon simulated with FLEXPART on (a) August 15 and (b) August 21. CA=Calgary, ED=Edmonton, GO=Golden, KA=Kamloops, KE=Kelowna, RD=Red Deer, RE=Regina, and VE=Vernon.

was to perform an hourly analysis of the transport patterns of smoke across North America.

Model output (Figure 3) shows prevailing winds carrying the smoke eastward toward central Canada. On September 5th, a sun photometer at Bratt’s Lake, located 30 km SSW of Regina, Saskatchewan, detected an increase in atmospheric aerosol optical depth [Environment Canada-Air Quality Research Branch, 2004]. At the same time, the surface PM2.5 levels measured at Regina stayed below 20 μg/m^3, indicating that the smoke plume remained aloft as it moved across southern Saskatchewan.

Acknowledgments

FLEXPART simulations were performed by Andreas Stohl at the Norwegian Institute for Air Research (NILU). §

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Air Quality Sampling during 2003 Prescribed Burns in Banff National Park; Part II

by Brian Wiens

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[This article is a continuation of "Air Quality Sampling during 2003 Prescribed Burns in Banff National Park; Part I", published in the Spring 2009 issue of the Canadian Smoke Newsletter. Ed.]

In 2003 Parks Canada carried out a series of prescribed burns in Banff National Park primarily to reintroduce fire into ecosystem cycling. Prescribed burns have the additional benefit of creating openings in contiguous forest that act as fire breaks and that inhibit pest infestations. For Environment Canada (EC) these prescribed burns provided an opportunity to sample and analyze smoke constituents to assess their contribution to pollutant loading in the atmosphere.

Because the burns were planned, it was possible to predict the path of the smoke with some accuracy and to deploy samplers near the burns in order to sample "young" smoke. EC only became involved several weeks prior to the planned burns and therefore had limited time to design a sampling program and prepare equipment. Due to these constraints, only existing equipment and readily available parts that met the criteria of portability and operability were employed.

It is important to note that this report summarizes a portion of the analysis carried out in 2003 and 2004. A number of other fire emissions analyses have appeared in the literature since that time. Their findings are not reflected in this article.

Forest and Fuel Conditions

Banff National Park has undergone some form of fire suppression for over a century. Historical evidence in the mountain parks suggests that a fire cycle of between 60 and 130 years was the norm until the mid 1940s when fire suppression "successfully" reduced the burning rate to near zero. This suppression has altered vegetation succession significantly. The ecosystem has responded by exhibiting a decline in native biodiversity due to increasing forest age, canopy cover, and continuity. These characteristics in turn have lead to more "habitat" for disease-carrying forest insects such as the mountain pine beetle (Dendroctonus ponderosae). They have also promoted the build-up of fuel for wildfires (Figures 1 and 2).

Figure 1. Banff valley aerial photo. Image taken circa 1924. Photo courtesy Parks Canada.

Figure 2. Banff valley aerial photo. Image taken circa 2000. Photo courtesy Parks Canada.

The Fairholme Range Prescribed Fire took place on the northeast side of the Trans Canada Highway in the Bow Valley between the towns of Banff and Canmore, as well as in adjacent valleys [Wiens, 2009]. The planned burn area totaled approximately 8500 hectares. In April 2003 fire managers began burning areas within the prescribed zones, with the aim of continuing the burns into the first week of June whenever conditions permitted. Conditions naturally reflected the balance between the need to contain the fire and the requirement to have fire behavior of sufficient intensity to burn substantial portions of the existing biomass. In addition to the planned fires, a fire which had remained dormant since spring flared up in August during dry conditions. In all, actual burned area totalled 5100 hectares by September 2003.

Sample Collection

The particulate samplers used in this study were Airmetrics portable programmable MiniVols, collecting PM2.5 and PM10. Filter holders used in the samplers were preloaded and bagged in a Parks building, and were therefore subject to a typical office environment's airborne dust loading and contaminants.

Parks Canada generously provided support in the form of personnel and helicopters. This enabled the team to deploy samplers in locations deemed likely to receive high concentrations of smoke. Samplers were installed at six sites and the sampling program carried out on three separate days. Minnewanka Ridge, Minnewanka Beach and Powerline collected PM2.5 only, with one pair of samplers programmed to sample during the afternoon, capturing emissions during the ignition and intense burning stages. The second pair were programmed to begin sampling late in the afternoon and continue overnight when fires were expected to be predominantly smouldering. The remaining three sites (Inglismaldie, Minnewanka Ridge2 and Repeater Ridge) were configured differently. Here, two pairs of samplers ran simultaneously during the afternoon fire ignition and flaming period, with one pair collecting PM2.5 and the second pair collecting PM10. At each of the six sites, loaded filter holders were placed alongside the operating samplers. These filters had no flow drawn through them and functioned as onsite controls.

The Minnewanka Ridge site was located directly above a burn. As a result, sampled smoke at this location was generally on the order of seconds to minutes old. Minnewanka Beach was close to the same burn, and sampled smoke less than one hour old. The Powerline site had burning nearby, with the most probable age for the bulk of the smoke on the order of one to two hours. Minnewanka Ridge2 was directly adjacent to a valley with intense burning and received smoke approximately one hour old. Inglismaldie was sampled during a period when no new fires occurred. Any smoke collected was therefore three hours or more in age. Repeater Ridge received smoke from several valleys with travel time ranging from 1-2 hours.

Once the filters had been retrieved

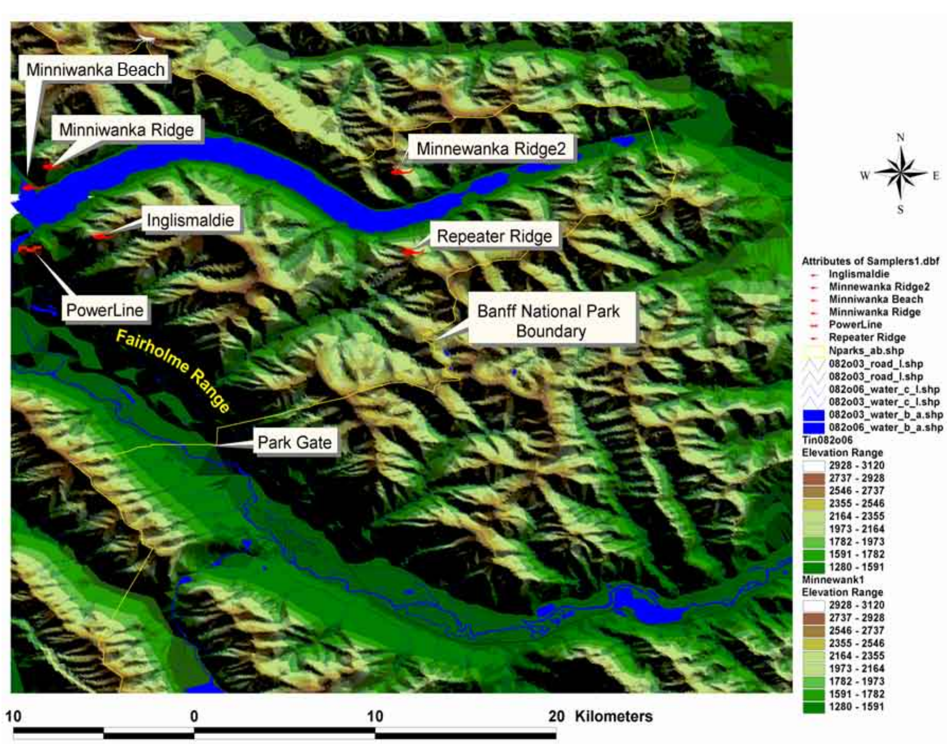

Figure 3. Map of study area with sampling sites.

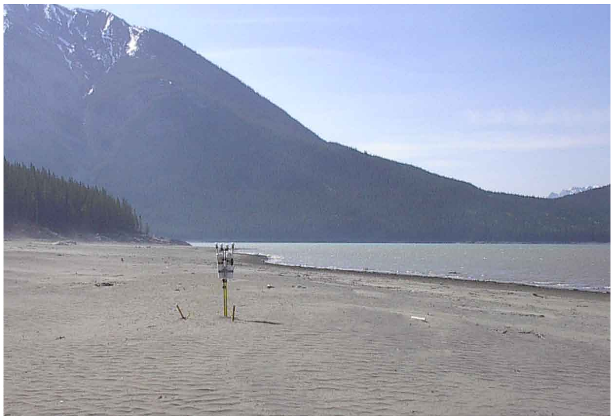

Figure 4. Minnewanka Beach sampling site.

Figure 5. Parks Canada helicopter and personnel deployed at Inglismaldie ridge site.

they were taken out of their holders, returned to glass containers and stored in a refrigerated box at temperatures between 4 and 6 °C until they were delivered to the lab for analysis.

Analysis

Alberta Research Council laboratories analyzed particulate matter on the filters gravimetrically and analytically for 65 elements and 22 polycyclic aromatic hydrocarbons (PAHs). Elements were analyzed using portions of loaded Teflon filters that were digested in nitric acid in a closed vessel at constant temperature. The digested solutions were analyzed using an Inductively Coupled Plasma-Mass Spectrometer (ICPMS) using a procedure patterned on EPA methods 3052 and 6020. PAH analysis was performed with a gas chromatograph mass selective detector (GC/MSD) system. The GC/MSD system was calibrated at the beginning of each sample run by the introduction of five concentration levels of the target PAHs. The calibration was checked at the completion of each run. Target quantities were calculated against internal standards added just prior to loading samples.

Results

Emissions from fire are the result of a variety of factors, two primary ones being fuel and fire behaviour. These in turn are influenced by precedent moisture, underlying soil, current weather conditions and terrain slope. Weather conditions such as wind speed, wind direction and relative humidity can change especially rapidly. As a

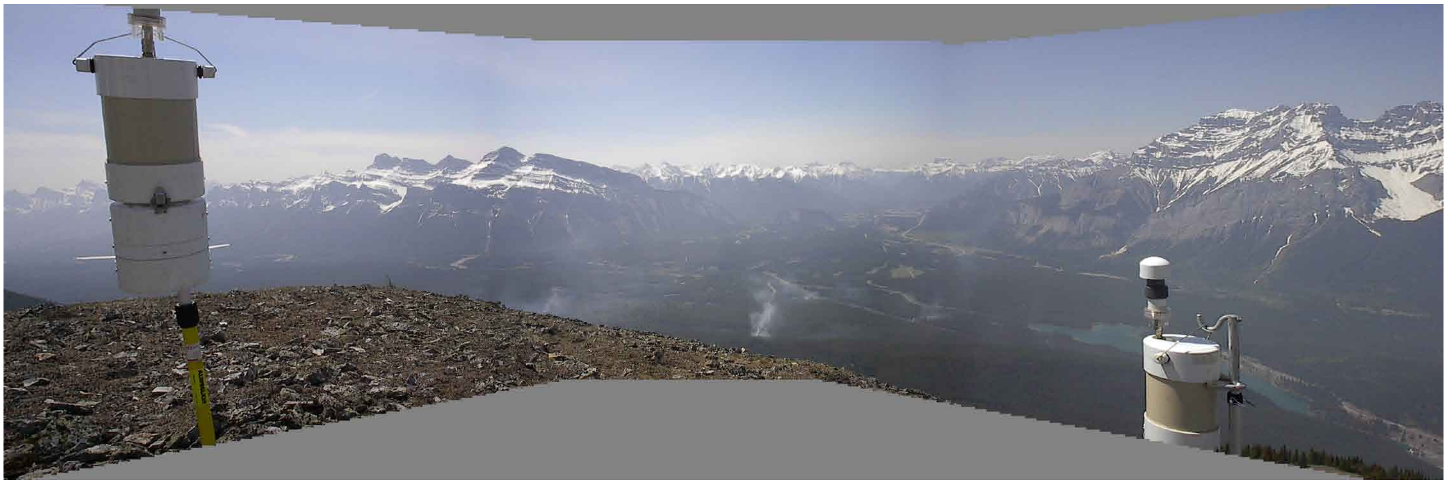

Figure 6. Panorama of filters installed on pole at Inglismaldie ridge sampling site.

result, fire behaviour is highly complex and variable in time and space. For simplicity this discussion will assume that:

a) fire behaviour occurred in two modes, predominantly flaming and predominantly smouldering, and

b) fuel was uniform across the region and during different burning periods.

At Minnewanka Ridge the calculated PM2.5 concentration was 1596 μg/m³ averaged over five hours of monitoring, which included a shorter period of intense fire lasting roughly two hours. At Powerline the fire was of longer duration with average PM2.5 concentrations of 748 μg/m³ over a period of nine hours and 489 μg/m³ over a subsequent five hour period. These values are consistent with exposure to nearby fire prior to substantial dilution of the smoke.

Conifer trees were the primary fuel during the Banff study. Resulting smoke would therefore be expected to exhibit properties consistent with conifer consumption. Several PAHs identified in the Banff data are considered markers of conifer smoke: Retene, benzo(b/k)fluoranthene, benzo(e)pyrene, benzo(ghi)perylene, and indeno(1,2,3-cd)pyrene. No markers considered unique to deciduous trees [Oros et al, 2000a and 2000b] were identified (Figure 7). Figure 8 depicts the effect of flaming vs. smouldering on the percentage of PAHs to total PM for various PAH species.

Also enlightening is a comparison between the results of the Banff filters and established conifer profiles such as the EPA profile (US EPA 2003) shown in Figure 9 (next page). The EPA profile represents the weighted average of six smouldering and seven flaming phase samples, while the Banff data profile represents three smouldering and four flaming phase samples. The selected filters and locations in these figures represent both fire modes and have the highest loading of PM. The error bars in the figures represent the relative percent uncertainty in the EPA conifer profile. Most of the Banff data resides within

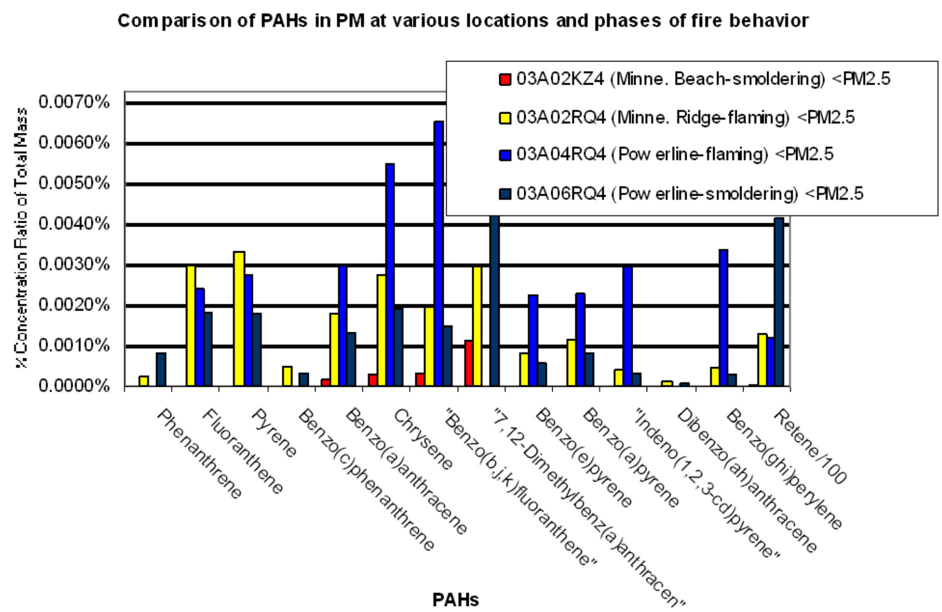

Figure 7. PAHs as a percentage of PM at Minnewanka Beach (smouldering phase), Minnewanka Ridge (flaming phase), Powerline (flaming phase) and Powerline (smouldering phase).

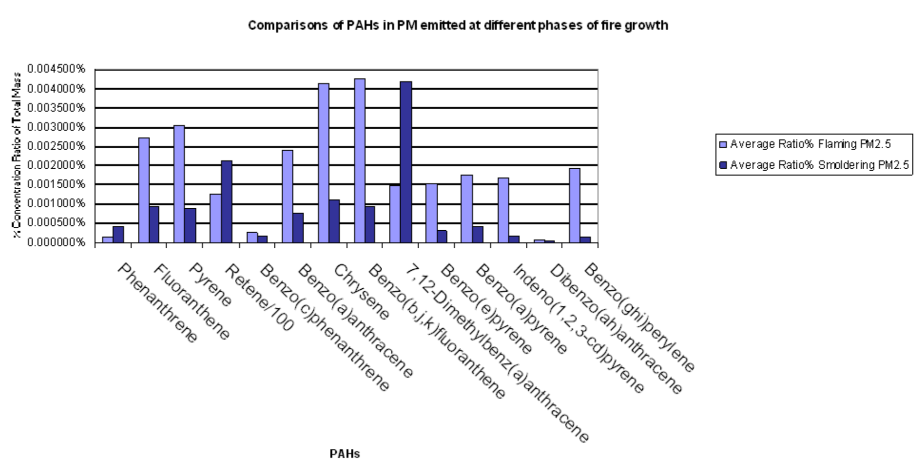

Figure 8. PAHs as a percentage of PM for various species. Predominant flaming phase depicted by light bar, predominant smouldering phase depicted by dark bar.

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this uncertainty.

Filters were also analyzed for elements. Several examples are presented in Figures 10a and 10b. Potassium is considered a marker of biomass burning particles emitted during flaming fires [Muraleedharan et al, 2000]. That study found that potassium, in emissions from tropical forest fires, accounted for between 10-20% of aerosol mass. The Banff results show much lower values for potassium with the highest proportion coming in at 1.1% of total mass at the Powerline site.

Martins et al. [1994] analyzed fire samples in Oregon, Washington and Idaho, and found that potassium, chlorine, manganese, calcium and zinc all have higher emission rates in the flaming phase and lower emission rates in the smouldering phase. This was confirmed in the Banff study. Conversely, chromium and nickel levels were lower during the flaming stage when compared to the smouldering phase.

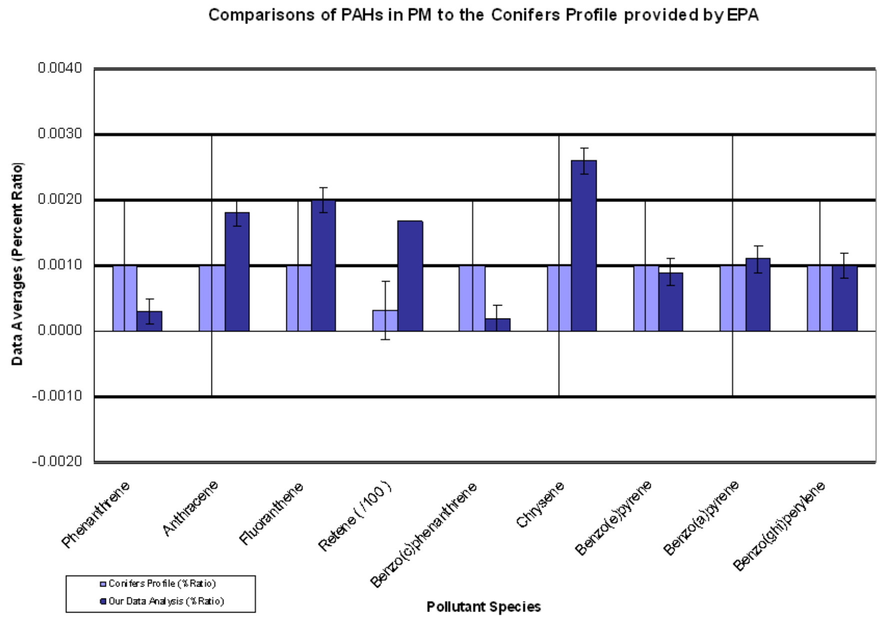

Figure 9. Comparison of EPA conifer PAH-PM ratios (light bars) to ratios measured in Banff study (dark bars).

This experiment also drew attention to the complex way smoke mixes out of fire and is transported in the atmosphere. The understanding of the science behind plume rise and dispersion is essential in order to predict smoke behaviour and downwind concentration. One approach to assessing plume rise would be to use photogrammetry to follow the evolution of the plume over time and to develop a three dimensional map of the plume which could be used to create and validate a model of plume rise. A simpler next step would be to take a series of observations of plume rise and plume height using something as simple as a clinometer

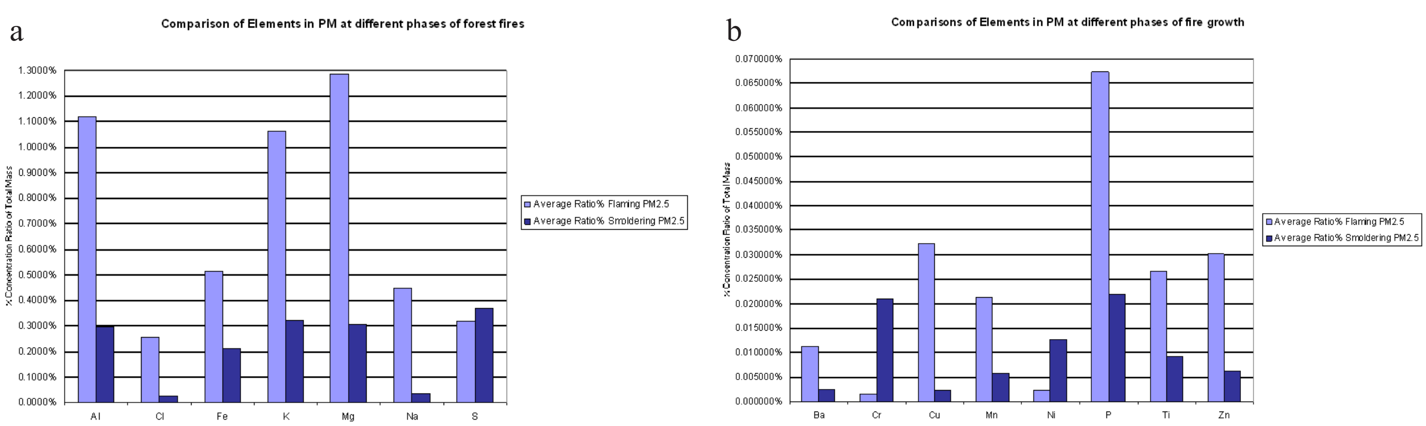

Figure 10. Comparison of percent of total mass for various elements. Flaming phase percentages are shown by the light bar, smouldering phase percentages are shown by the dark bar.

and then apply simple trigonometry to estimate height and development speed. These observations, combined with knowledge of atmospheric conditions, should facilitate development of at least a rudimentary plume behaviour model suitable for biomass smoke modelling.

Alternative Approaches

The short time available to assemble equipment largely dictated the scope of this sampling program. The results, while interesting, have a high level of uncertainty. For example, many PAHs are fairly volatile and may have been lost due to the filter system used. A sequential system of multiple filters would have been better able to capture the complex mix of constituents. Probably most important improvement to the sampling program would have been to ensure that elemental carbon and organic carbon could be reliably characterized. In all likelihood, this would have substantially reduced the amount of unresolved mass.

It would also have been useful to sample gaseous species such carbon monoxide, carbon dioxide, nitric oxide and nitrogen dioxide and to collect SUMMA canisters for VOCs. There remains a fairly high degree of uncertainty as to the composition of emissions from fire, so future experiments have the potential to realize significant gains in understanding of fire emissions as they relate to atmospheric chemistry.

Conclusions

Particulate monitoring close to forest fires was carried out in association with prescribed burns in Banff National Park. Samples provided an indication of the intensity of fire and the species represented in smoke. Measurements were generally consistent with other studies, albeit with variations due to differences in fuel species, fuel density, underlying soil and topography and experimental error.

Further studies would be substantially enhanced by analysis of the carbon (elemental and organic) portion of the PM. Gaseous chemistry would also provide valuable clues as to the character of the fire during sampling. Age of the smoke was estimated in this study but should be more rigorously determined in any subsequent sampling. §

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Papers of Interest

The Untold Story of Pyrocumulonimbus

Preliminary paper accepted for publication in the Bulletin of the American Meteorological Society; by Michael Fromm, Daniel T. Lindsey, René Servranckx, Glenn Yue, Thomas Trickl, Robert Sica, Paul Doucet, and Sophie Godin-Beekmann.

A pyrocumulonimbus (pyroCb) is a thunderstorm that is either initiated by or augmented by fire. Extreme pyroCbs can reach through the tropopause well into the lower stratosphere (LS) where they inject huge amounts of smoke and related biomass emissions.

The mechanisms of transport for aerosols into the LS were previously believed to be slow cross-tropopause ascent in the tropics, and episodic injection by volcanoes. Since 2000, observations of pyroCbs and their effects on the LS have become more frequent, and the pyroCb has come to be understood as a unique form of convection with respect to cloud physics and prolonged lifetime, and also as another major mechanism by which aerosols are transported into the LS. The paper mentions that a single pyroCb in 2001 injected a mass greater than 5% of average annual northern hemispheric LS background levels into the LS. The authors then move into an investigation of three previous cases where LS aerosols had been attributed to volcanoes:

- August 1989. Lidar signals at Salt Lake City indicated depolarizing LS layers. Previous investigations pointed to volcanic origin, specifically from the Santiaguito volcano in Guatemala. Reinvestigation using lidar, Stratospheric Aerosol and Gas Experiment (SAGE) and Advanced Very High Resolution Radiometer (AVHRR) data as well as Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) back trajectories resulted in attribution of these signals to multiple pyroCbs which occurred on July 21 over Manitoba, Canada.
- Summer 1990. SAGE aerosol profiles indicated a sudden and substantial increase in LS aerosol loading in high and northern mid-latitudes. Investigators attributed this phenomenon to an unreported volcano. Based on reanalysis of northern latitude SAGE data from fall of 1990 and investigation of AVHRR data for July, the authors conclude that the most likely source for the LS aerosols was a northern Alaska pyroCb which occurred in early July.
- June 1991. Again, SAGE measurements indicated LS aerosol layers over the Atlantic at high and northern mid-latitudes, but with sizes and at altitudes at odds with historical volcano aerosol characteristics and behaviour. Initially attributed to the Mt. Pinatubo eruption, a second investigation found that backscatter values from an ozone lidar over Germany were indicative of aerosols on the order of several days old. In addition, back trajectories consistently indicated a flow eastward across the Atlantic from northeastern North America. This, together with the fact that most Mt. Pinatubo aerosols were confined within 20 degrees either side of the equator, lead the authors to identify two June pyroCbs over southern Quebec as the culprits.

A survey of the fire season over North America from May to September 2002 was carried out in order to determine the frequency of pyroCb activity. Total Ozone Monitoring Spectrometer (TOMS) Aerosol Index (AI) data played a critical role. AI spikes were used to initiate back trajectories, which in turn pointed to certain upstream locations for further investigation using Geostationary Operational Environmental Satellite (GOES) imagery. This lead to the identification of 17 pyroCbs, nine of which occurred between June 18 and July 1 of 2002.

After surveying the 2002 season, the authors then discuss a number of pertinent characteristics of pyroCbs, namely:

- on GOES imagery, clouds are anchored to fire hotspots with a brightness temperature < -40 °C at 10.7µ and > +10 °C at 3.9µ
- environmental conditions are different from those favouring severe thunderstorms. The Haines Index is very high – usually 6 – indicating strong low level instability and dry conditions which promote fire spread
- the effective maximum height of the outflow is the same or higher than a convective cloud top, with the average tops in 2002 at 11.6 km AMSL/223 hPa, and
- the bulk of pyroCbs reach diurnal maturity around 6 pm local time, at which point a significant amount of biomass emissions are being transported above the region of precipitation and scavenging processes into the upper troposphere and lower stratosphere.

The authors finish by mentioning pyroCbs and LS layers associated with well known fires in China and the US in the late 1980's and suggest that there is a need to further explore how often this phenomenon occurs in the boreal forests of Asia, as well as to maintain the capability to monitor using nadir and stratospheric imagers aboard satellites. §

(summary by Al Pankratz, Air Quality section, Prairie and Northern region, Environment Canada)