The Canadian Smoke Newsletter

Fall 2008

A newsletter dealing with smoke-related issues relevant to Canada

Welcome to the Fall 2008 issue of ***The Canadian Smoke Newsletter***. We are pleased at the positive response to the inaugural Spring 2008 edition of the CSN, and happy to see it being distributed internationally as well as domestically. We hope that it will be useful and informative to a wide audience. If you are an international reader, please feel free to contribute articles as well, as the science of and issues to do with smoke are not confined to the borders of Canada. Author guidelines are included on the final page.

If you plan to attend a fire or smoke related conference in 2009, you may wish to consider the following:

- EPA 18th Int'l Emission Inventory Conference, Baltimore, April 14-17
- European Geosciences Union General Assembly, Vienna, April 19-24
- AGU (ARCTAS sessions), Toronto, May 24-27
- AWMA 102nd annual conference and exhibition, Detroit, June 16-19
- Int'l Wildland Fire Conference, Sydney, Australia, June 18-20
- 8th Symposium on Fire and Forest Meteorology, Kalispell, Oct 13-15
- AGU (ARCTAS sessions), San Francisco, Dec 14-18

Also, transactions from the 2008 1st International Conference on Forest Fires: Modelling, Monitoring and Management in Toledo, Spain are hosted at http://library.witpress.com/pages/listPapers.asp?q_bid=450 (payment required).

As always, many thanks go out to the contributors and colleagues who made this issue possible.

Al Pankratz

NASA DC-8 and P-3 on the tarmac at CFB Cold Lake during ARCTAS study, July 2008. Photo courtesy of NASA.

In this issue:

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ARCTAS: The Perfect Smoke

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Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) is an international, interdisciplinary field campaign established under the auspices of the International Polar Year (IPY) and primarily conducted during the spring and summer of 2008. ARCTAS is a major component of the IPY-sanctioned POLARCAT (Polar Study using Aircraft, Remote Sensing, Surface Measurements and Models of Climate, Chemistry, Aerosols, and Transport) project aimed at analyzing and quantifying the impact of major sources of pollution on the Arctic. POLARCAT involves a consortium of countries (i.e., United States, Canada, Germany, France, Norway and Russia) and agencies (including the National Aeronautics and Space Administration [NASA], National Science Foundation, National Oceanic and Atmospheric Administration, and Department of Energy for the United States) and an ensemble of aircraft, surface and ship based measurement platforms (http://www.espo.nasa.gov/arctas/ and http://zardoz.nilu.no/~andreas/POLARCAT/). ARCTAS is a leading partner of POLARCAT through its deployment of high altitude, long range aircraft and complementary specialized aircraft, its link to satellite observations, and its engagement of models in mission design and execution. Taken together with the ensemble of POLARCAT and broader IPY activities, ARCTAS offers an unprecedented opportunity for contribution to an integrated arctic research program.

It is predicted that northern hemisphere upper latitudes will be the harbinger for climate-related temperature increases and change, and in fact these are the regions that are rapidly warming and have already shown the initial signs of climate change [Flannigan et al., 2001; Chapin et al., 2006; Soja et al., 2007]. As Arctic and boreal regions warm, it is imperative to understand the feedbacks to and from these regions, as they interact with the climate system. For instance, climate change is predicted to result in increasing boreal fire activity (area burned, frequency and severity), with direct and indirect impacts on the climate system [Stocks et al., 1998; Campbell and Flannigan, 2000; Dale et al., 2001; Flannigan et al., 2005; IPCC, 2007]. The immediate release of emissions and the potential release of mercury can directly affect air quality and human health [Mott et al., 2002; Sigler et al., 2003; Rittmaster et al., 2006; Turetsky et al., 2006; Hall et al., 2008], and also act as a direct feedback to the climate system by increasing greenhouse gas levels and by altering aerosol radiative forcing [Forster et al., 2007]. The transport and deposition of pyrogenic black carbon to snow and ice decreases surface albedo, which could accelerate melting. Chemical reactions in smoke plumes lead to the formation of tropospheric ozone, which exerts significant climate forcing in the Arctic. Also, pyroconvective events can inject smoke to the lower stratosphere, where it is long-lasting and can influence the climate system by affecting the radiation balance and stratospheric chemistry [Fromm et al., 2000; Fromm and Servranckx, 2003].

There are four major ARCTAS scientific themes.

1. Long range transport of pollution to the Arctic including arctic haze, tropospheric ozone, and persistent pollutants such as mercury;

2. Boreal forest fires and their implications for atmospheric composition and climate;
3. Aerosol radiative forcing from arctic haze, boreal fires, surface deposited black carbon, and other perturbations; and
4. Chemical processes with a focus on ozone, aerosols, mercury, and halogens.

Boreal fires are an integral component to several of the major ARCTAS themes.

The ARCTAS field campaign included two major field deployments during the spring (April 1 – 20) and summer (June 18 – July 13) of 2008. The spring deployment, based out of Fairbanks, Alaska, focused on the long-range transport of pollutants to the Arctic and the resultant arctic haze. Unexpectedly, a significant amount of the arctic pollution at this time originated from southern Siberian biomass burning. The summer deployment focused on anthropogenic aerosols in California and the effect of the deposition and transport of pyrogenic aerosols and pollutants, primarily from boreal Canada. It was the aim of both of these campaigns to investigate the transport of emissions that impinge on human health and modify regional and global climate. In this letter, our primary concentration is on boreal Canada, which was inundated with smoke from North America as well as the Far East, Russia, during the second ARCTAS field campaign.

ARCTAS Summer Campaign – Focus on Canadian Boreal Fires

A large interdisciplinary group of more than 150 scientists and support personnel assembled at the 4 Wing Canadian Forces Base in Cold Lake, Alberta, Canada from June 26 through July 12, 2008, with the sole purpose of investigating atmospheric pollution from boreal forest fires and the interactive feedbacks between the Arctic environment, fire, weather and climate. During this period, two NASA aircraft (a DC-8 and P-3B) were based in Cold Lake, while a NASA B-200 aircraft was located in Yellowknife, Northwest Territories. Flight operations were coordinated through a control centre in Cold Lake, where most scientists and project managers were located. Daily briefings and planning sessions were held to determine the status of the forest fire situation across Canada, and to plan fire monitoring and smoke sampling flights. During the deployment period a total of 42 flights occurred (9, 12 and 21 sorties for the DC-8, P-3B, and B-200 respectively). These flights were primarily focused on boreal fires in northern Saskatchewan, but involved sampling and tracking smoke from the Yukon to Greenland.

The Canadian forest fire season developed slowly in 2008, and indeed much of the country experienced very little fire activity throughout the fire season. However, Saskatchewan and the Northwest Territories had significant fire activity, particularly in northern Saskatchewan during and following the ARCTAS campaign. Of the 1.5 million hectares (Mha) that burned in Canada this year, Saskatchewan fires accounted for more than 1.1 Mha, with 0.75 million hectares burning in the remote regions of northern Saskatchewan. The selection of Cold Lake as an operating base involved analysis of seasonal fire activity across Canada over the past half-century, which indicated that this region was most likely to burn during the late-June through early July period, and this proved to be the case in 2008. Forest fires in northern Saskatchewan, and many regions of northern Canada, are usually allowed to burn naturally unless interests of value are threatened. These remote fires tend to be larger than those in regions where fires are actively suppressed, providing ample target opportunities for the NASA aircraft.

From a scientific perspective, the diversity of fires that burned in close proximity to the air base could not have been more ideal for reducing aircraft transit times and increasing on-site sampling and measurement capabilities. During the summer ARCTAS period the only significant fire danger conditions existed in west-central Canada, and high to extreme fire danger was common across northern Saskatchewan and the southern Northwest Territories. Consequently, Saskatchewan began experiencing a higher than normal fire load in the province's observation zone, coinciding with the arrival of the research team. The fires burning in the region exhibited behavior commensurate with these fire danger levels, spreading quickly as intense surface fires or as intermittent or continuous crown fires. These fires developed smoke columns reaching 5-7 kilometers (km) in altitude, however fire weather was not conducive to the sustained continuous crown fires that are common under continuous extreme conditions in boreal regions, which could have produced smoke columns approximately twice the altitude as those observed. Widespread precipitation occurred in this region midway through ARCTAS, quieting most Saskatchewan fires. However, those fires in the extreme north (Lake Athabasca area) were not affected and continued to exhibit strong fire behavior through the ARCTAS period and beyond. On the day the researchers departed Cold Lake, burned area had reached 2.5 times the 20-year mean in Saskatchewan, and by the end of the fire season, burned area was over 4 times the 20-year mean (Figure 1).

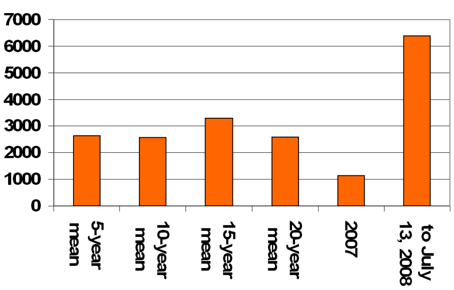

Figure 1. Area burned (km²) in Saskatchewan

Even though these conditions presented unprecedented scientific opportunities, exposure to smoke adversely affects human health and these fires stressed several local northern communities and fire fighting organizations. During the field campaign, Uranium City, Deschambault Lake, Pelican Narrows, Black Lake, Sandy Bay, Stony Rapids and Fond-du-Lac evacuated almost 3000 people and many were left behind to fight the fires. On June 29th, 102 fires were burning and more than half of those ignitions resulted from lightning strikes that occurred within the previous 24 hours. In the first week of July, there were 30 helicopters and 17 fixed-wing air tankers battling the wildfires, with fire crews from the Northwest Territories, Manitoba, Ontario and Quebec aiding in the protection of threatened communities.

There is an immediate and distressing human dimension to wildfires, however the scientific information gathered during these "naturally" occurring wildfires will aid humankind by providing necessary information concerning feedbacks to and from the climate system.

Daily Fire Support from the "Fire Canada" Team

During the Cold Lake deployment, our team provided daily and intensive support for flight planning for the P-3, B200 and DC-8 aircraft, as well as continuous real-time in-flight aircraft support. Using our extended community (i.e., Canadian Forest Service, Colorado State, University of Maryland [UMD]), we provided daily briefings that included fire weather, fire danger conditions, and predicted fire behavior. We mapped active fire locations and estimated their potential for growth, identified potential regions for pyroCu (pyro-cumulus) and pyroCb (pyro-cumulonimbus) development, and updated satellite data for Siberian and North American fire and smoke transport (Figure 2 below, and Figure 3, next page). Additionally, by using instant text messaging and uploading images to the aircraft, we were able

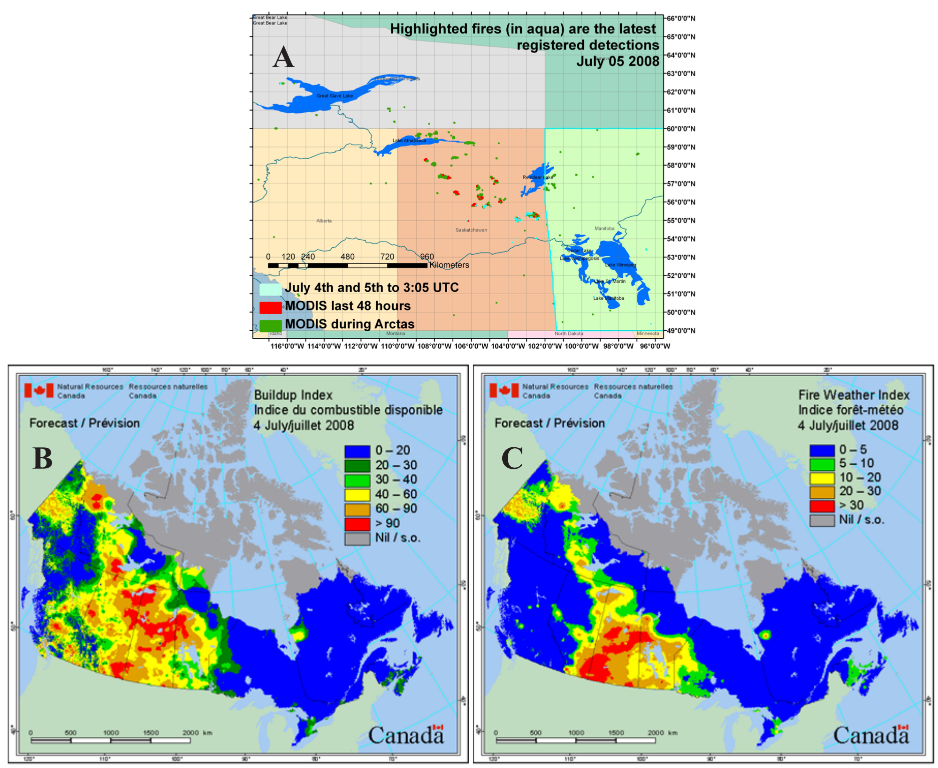

Figure 2. Examples of maps provided to the aircraft and scientific crews.
A. Medium-scale active fire location map. Continental and single fire location maps were also provided. The fire detection data were downloaded several times per day (as needed) from the Fire Information for Resource Management System (FIRMS) located at UMD. (http://maps.geog.umd.edu/firms/shapes.htm).
B and C. Buildup index and Fire Weather maps were taken from Natural Resources Canada. We also provided fire potential estimates based on local weather station data throughout the day.

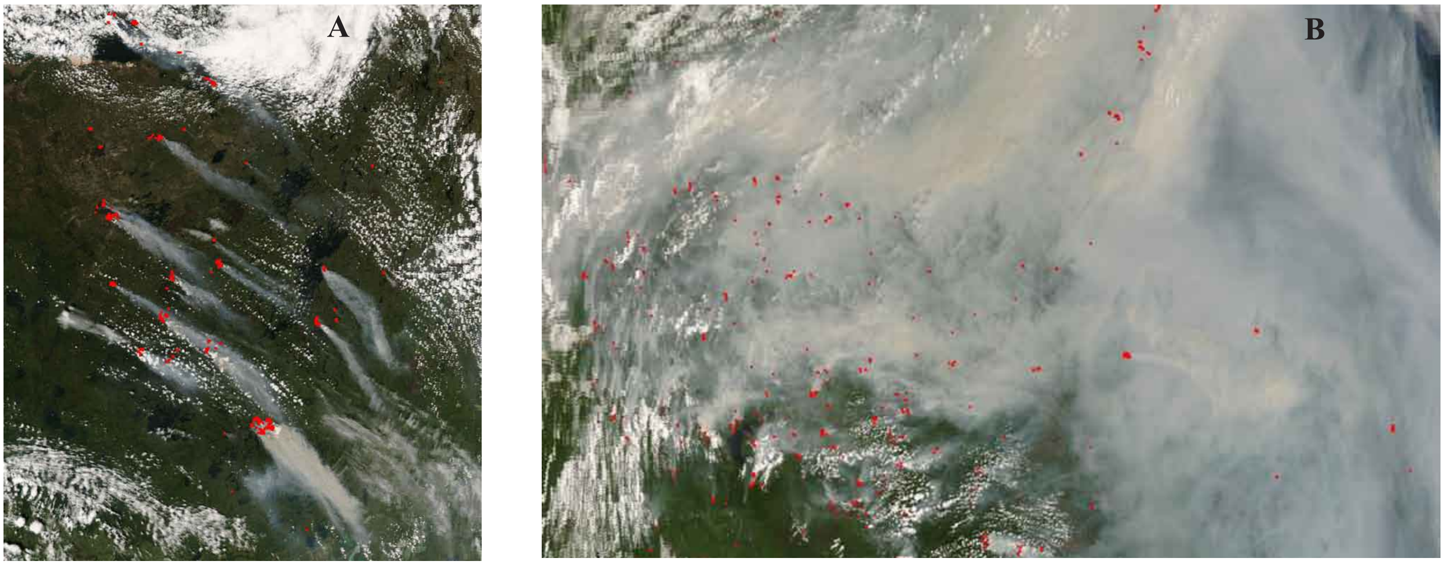

Figure 3. MODIS imagery of active fire detections and streaming smoke. A. Smoke streams from fires in this MODIS Aqua image of Saskatchewan, June 30, 2008. B. This MODIS Terra image from July 1, 2008, shows fire and smoke blanketing the far east of Siberia. This smoke was transported to North America, where it was sampled near the coast of British Columbia and near Greenland. These images were downloaded from the MODIS Rapid Response System website http://rapidfire.sci.gsfc.nasa.gov/.

to provide in-flight updates to aircraft crews and scientists with continuous weather, fire location, fire weather and smoke information to aid in guiding the aircraft to favorable sampling opportunities.

The result was an unprecedented in-situ boreal aircraft campaign that will provide valuable information for teasing apart connections between and feedbacks to and from the Arctic, fire, weather and climate systems. A variety of chemical species were sampled from active and smoldering plumes at numerous heights in the atmosphere and at varying distances from plumes (Figure 4).

Figure 4. Flaming and smouldering smoke plumes, Saskatchewan, ARCTAS 2008. These photos were taken from the P-3 by Dr. Tony Clarke, who is a member of the University of Hawaii's HiGEAR (Hawaiian Group for Environmental Aerosol Research) team.

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Lidar was used to capture the vertical profile of smoke plumes from satellites and aircraft. Using visual information, satellite imagery and chemical transport models, both Siberian and North American (primarily Saskatchewan) smoke plumes were sampled. Chemical transport models were able to accurately provide the latitude, longitude, altitude and time at which the Siberian smoke plumes would be in close proximity to the aircraft. Additionally, the aircraft sampled smoke from a pyroCb and several pyroCu plumes (Figure 5).

Additionally, we are collaborating with researchers from Saskatchewan, the Canadian Forest Service and several universities to add ground-based information, which will facilitate closing the research loop, from the fuel mass on the ground to the emissions to the atmosphere. Specifically, in

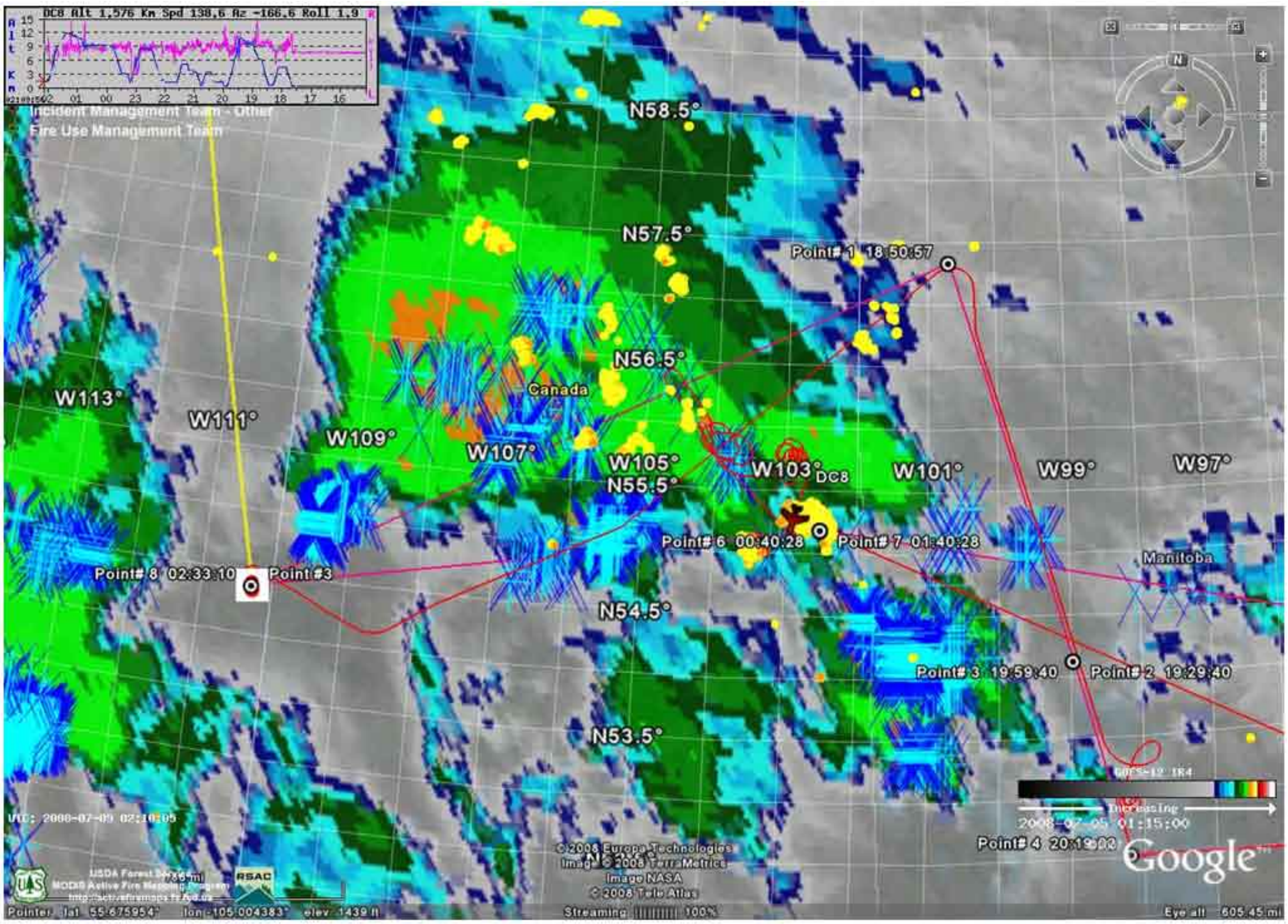

Figure 5. Screen shot (July 5th) from the NASA Real Time Mission Monitor (RTMM) , which is a tool that integrates satellite, airborne, model and surface data for field experiment management. The imagery is GOES overlaid on Google Earth, and the Blue X's are lightning strikes. Red is a MODIS active fire detection sensed within 12 hours of the present; orange is between 12-24 hours; and yellow is from 24 hours to 6 days. The actual plane track is indicated by the red line, and the DC-8 is represented by the small plane. The DC-8 flew through the smoke-filled cumulus clouds (pyroCu) that are evident in the center of the view; the higher, colder cloud tops are light greens, reds and oranges (scale on bottom right). The plane's altitude over the entire flight is shown with the blue line in the graph at the top left of the screen. Evolved smoke from a pyroCb that erupted the previous evening was sampled from the DC-8 in the Northwest Territories on June 29, 2008.

collaboration with the Canadian Forest Service, a team of researchers from the University of Guelph and McMaster University, who were funded by the Natural Sciences and Engineering Research Council of Canada (NSERC), conducted ground-based surveys in the Saskatchewan wildfires to assess fuel consumption rates and post-fire changes in soil climate conditions. The field sampling included organic soil characterization, assessments of fuel structure, and measurement of consumption severity via the Composite Burn Index and rates of duff consumption in several locations within the Mirond Lake fire. These data will be valuable for ground-truthing satellite measurements and verifying modelled emissions.

Data Availability

It is essential to complete the research loop by connecting the amount of biomass consumed on the ground to the injected and transported smoke, and then to the in-situ aircraft measurements, the satellite measurements and the models that simulate smoke transport and its chemical evolution. To develop these connections, data collected using NASA and NSERC funding will be made publicly available following an appropriate amount of time, which is designed to extend scientific courtesy to the initial investigators. Mission data are currently available from the NASA Langley DAAC (http://www-air.larc.nasa.gov/data.htm). The ultimate goal is not only to have unfettered access to data, but to foster collaborations across the various components of ARCTAS, POLARCAT and the larger research communities to maximize the scientific value of the ARCTAS observations in the broader context of IPY research. The three official phases of ARCTAS are: the field phase (April 1 – July 15, 2008); the research phase (up to July 15, 2009) and the public phase (July 15, 2009 and onward). §

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The International Workshop on Advances in Operational Weather Systems for Fire Danger Rating

by Michael Brady, Canadian Forest Service

The International Workshop on Advances in Operational Weather Systems for Fire Danger Rating was held in Edmonton, Alberta from July 14-16, 2008. Over 75 meteorologists, fire scientists, managers and policy makers from 25 countries met at the Northern Forestry Centre in Edmonton to discuss meteorological applications and monitoring systems used to assess fire danger. This meeting was organized jointly by the World Meteorological Organization (WMO), the panel for Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) and Natural Resources Canada's Canadian Forest Service (CFS).

The focus of the meeting was on current fire danger rating practices used around the world and ways in which nations could cooperatively improve them. The meeting began with attendees describing approaches used to monitor fire danger in their respective countries. This was followed by breakout sessions to discuss specific areas of fire danger system enhancement. These included:

- Weather observations and networks (access and adequacy of in-situ data, use of remote sensing, etc.)
- Data management (collection and storage, spatial processing and display, dissemination)
- Weather analyses (fire weather normals, short and medium term weather forecasts)
- Approaches to defining and evaluating fire danger levels (calibration, validation)
- Complementary indices of fire danger (live vegetation, curing, soil moisture, etc.)
- Smoke forecasting and monitoring (emissions, dispersion, etc.)

The opening presentation in the smoke forecasting and monitoring breakout session was delivered by Orbita Roswintiarti from the Indonesia Space Agency. Entitled "Regional Haze Forecasting in Southeast Asia", it presented the historical context for smoke monitoring in Southeast Asia. After the 1998 El Niño fire and smoke disaster, efforts have been made to better predict smoke and haze events within the region.

Steve Sakiyama from the British Columbia Ministry of Healthy Living and Sport presented "Western Canada BlueSky Pilot Project", a collaborative effort to adapt BlueSky for Alberta and British Columbia. BlueSky is a smoke modelling framework governed by the BlueSky Consortium with the USDA Forest Service AirFire Team taking the lead responsibility for scientific development. It has been used to model smoke emissions and transport for planning purposes.

Bryce Nordgren of the US Forest Service gave a presentation entitled "Air Quality Forecasting." This talk summarized the current efforts of the Fire, Fuel, and Smoke Science Program (FFS) of the Rocky Mountain Research Station (RMRS) at modelling the impacts of smoke on air quality in the US, based on MODIS hotspot detections.

An "Update on ARCTAS 2008 Study" was given by Amber Soja, National Aeronautics and Space Administration. The Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) study has been investigating the long-range transport of aerosols in the atmosphere, and this portion of the project conducted sampling for several pyrocumulus clouds in northern Saskatchewan in June and July of 2008.

Finally, Kerry Anderson of the Canadian Forest Service presented new ideas and methods for "Smoke Emissions Estimates." Issues to do with various methods of using hotspots were presented along with possible ways to calculate plume penetration height.

These presentations served as a springboard for the discussion, which focused on four specific issues: Plume Rise and Development, Emissions, Applications and Challenges.

Estimating the heights of plume rise was seen as a crucial factor in predicting smoke dispersion. To address the issue the group recommended theoretical and numerical model development. This will require assembling necessary datasets for validation (as many exist but are not being used), and may also require additional observations.

Smoke emissions were seen as an important element affecting the public. Emissions from fires determine the chemical composition of the smoke, and a more complete understanding of the processes was seen as an important step towards addressing the problem. Recommendations included a literature review on emission factors, including unpublished information; defining differences between smouldering and flaming combustion; and developing regionally specific factors.

There was much discussion over potential users of smoke forecasts, as applications must be driven by user needs. The group recommended doing a needs analysis to determine product development, and then to prioritize tasks accordingly.

Finally, present technological challenges still facing smoke forecasting systems were addressed. These include technological infrastructures, satellite lifetimes, etc. Group recommendations included centralized data storage and servers, as well as the exchange of information through an email distribution list.

In summary, the workshop provided an interesting overview of fire danger rating methods used around the world. Through the break-out sessions, various topics were addressed, stimulating dialogue and possible collaboration. An e-mail discussion group has been started for those interested in smoke forecasting issues. Anyone interested in joining the discussion group should contact Kerry Anderson at *kanderso@nrcan.gc.ca*. A full report of the workshop is also being prepared. §

Wildfire Smoke Forecasting for British Columbia and Alberta: The BlueSky Western Canada Extension Pilot Project - Update on Progress

by Steve Sakiyama, BC Ministry of Healthy Living and Sport

The Spring 2008 issue of the CSN provided a description of a smoke forecasting pilot project undertaken by Canadian provincial and federal agencies in British Columbia and Alberta. The pilot project involves the application of the US Forest Service BlueSkyRains smoke forecasting system to these provinces. The goal of the project is to have an operational system that provides smoke forecasts from wildfires up to 48 hours into the future for this domain. It involves the use of meteorological forecast model output and wildfire smoke emissions estimates processed by a computer loaded with the BlueSky framework software operating at the University of British Columbia (UBC). The output would be in a user-friendly GIS based format that would provide forecast trajectories and PM2.5 concentrations.

Over the past year, UBC has been producing hourly meteorological model output for the entire domain at 4 km grid resolution with the eventual goal of ingestion into the BlueSky framework computer. Additionally, during this past summer the BlueSky framework software has been further developed and is currently in testing phase. More recently Sonoma Technologies and the Canadian Forest Service (Northern Forestry Centre) have been working together to develop an emissions module for ingesting daily fire information from the Canadian Wildland Fire Information System. This module with its associated data links will be installed and tested on the UBC BlueSky computer by December 2008, with the goal of system operation and testing early in 2009.

We would like to acknowledge the contributions from our agency partners. Special thanks to Kerry Anderson (Northern Forestry Centre) for his efforts on the emissions component of the framework. §

If you have any questions about this pilot project, please email Steve at Steve.Sakiyama@gov.bc.ca

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Calculating Canadian Wildfire Emissions for Historical Analysis and Air Quality Forecasting Purposes

by David Lavoué, Consultant for the Air Quality Research Branch, Environment Canada, Toronto

Canadian wildfires have a significant impact on air quality and climate at regional and continental scales. They release numerous chemical species, including greenhouse gases (GHG), ozone precursors, and particulate matter (PM). Increased levels of fine PM affect people's health, especially seniors, infants, and people at risk [Henderson and Brauer, 2008]. Moreover, submicron aerosols emitted during forest fires affect the amount of solar radiation incident on the earth's surface and lower atmosphere. Carbonaceous material is a major constituent of the combustion aerosol. It is comprised of black carbon (BC) and organic carbon (OC) which have distinct radiative properties. BC absorbs sunlight like a black body and heats the surrounding air. Jacobson [2001] estimated that BC may have the second strongest warming effect after carbon dioxide. On the other hand, OC has light scattering properties similar to sulphate, and reflects a part of incoming solar radiation back to space, causing cooling.

A fire's hourly fuel consumption and rate of spread can be calculated by applying the surface meteorology from the Canadian weather forecast model GEM (Global Environment Multi-scale) to the Canadian Fire Behaviour Prediction (FBP) System [Forestry Canada Fire Danger Group, 1992]. An S-shaped fire growth parameterization is used to assess the variation in area burned between the start-up, acceleration, and slowdown phases during its active period. Emission factors for 20+ gaseous and particulate species are then applied to fuel consumption numbers to calculate hourly emissions. The algorithm includes an assessment of the convection column height, also called injection height. It is approximated from the heat flux, which is a function of the area burned, fuel consumption, and low heat of combustion for wood material. The injection height is a key parameter of pollutant dispersion and long-range transport. The method used to calculate the 3D emission fields was extensively detailed in Lavoué et al. [2007].

We intend in the future to regularly upgrade the algorithm to provide a better assessment of Canadian wildfire emissions. For instance, peatland burning, which may be a large emission source in some Canadian regions, will be taken

Bottom-Up Method for Calculating Forest Fire Emissions

The following is a simple bottom-up approach to assess emissions from wildland fires. Emissions can be calculated following Seiler and Crutzen [1980]'s equation. The amount (Q) of chemical species (X) emitted is determined by applying an emission factor to the estimates of area burned and fuel consumed:

$$Q(X) = A \times B \times EF(X)$$

with A = area burned (hectares), B = fuel consumption (kg/m^2), and EF = emission factor (grams of chemical species X per kilogram of dry matter).

Consider a section of forest with the following characteristics:

- area is 100 hectares
- 60% and 40% of the fuel consumption occurred during the flaming and smouldering phases respectively
- for simplicity, no unburned areas are considered
- fuel consumed per unit area is 2.0 kg/m^2
- literature review shows that the PM2.5 emission factor is 14.0 g/kg of dry fuel (flaming), and 22.9 g/kg of dry fuel (smouldering)

The amount of PM2.5 emitted by the flaming area is:
1,000,000 m^2 **x** 0.6 **x** 2.0 kg/m^2 **x** 14.0 g/kg = 16,800,000 g or 16,800 kg of PM2.5.

The amount of PM2.5 emitted by the smouldering area is:
1,000,000 m^2 **x** 0.4 **x** 2.0 kg/m^2 **x** 22.9 g/kg = 18,320,000 g or 18,320 kg of PM2.5.

The total amount of PM2.5 emitted is 35,120 kg or 35.12 tonnes.

A more in-depth treatment of these emissions requires consideration of hourly/daily assessment of burned area, hourly fuel consumption based on weather, and more accurate EFs based on combustion phase. Such work is currently underway.

into account in the fuel consumption numbers. Furthermore, other chemical species, such as metals (e.g., mercury) will be added to the emission factor database.

Construction of an Historical Database

A first application of the newly developed algorithm was to obtain a set of forest fire season emissions to cover different scenarios for air quality studies. Emissions were calculated for five consecutive years from 2000 through 2004 [Lavoué et al., 2008]. The years 2000 and 2001 were characterized by below average fire seasons. However, the three subsequent years exhibited large fire emissions in several regions across the country.

In the summer of 2002, the smoke released by about 150 wildfires in central Quebec covered southeastern Canada and the northeastern US for several days. These fires contributed 84% and 71% of the provincial annual PM2.5 and BC emissions, respectively. Fine particulate matter sources were included in Environment Canada's CHRONOS air quality model, allowing significant improvement in the simulation of particle concentrations for surface monitoring sites in eastern Canada and the northeastern US [Rousseau and Lavoué, 2005].

With respect to 2003, the fire season was extreme in the western and central provinces with numerous air quality degradation episodes occurring due to smoke. The gridded PM2.5 emission map (Figure 1) shows significant emissions in British Columbia, Manitoba, and Ontario.

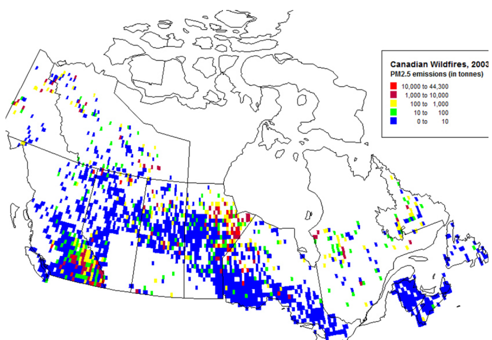

Figure 1. Gridded PM2.5 emission amounts from wildfires.

Figure 2 emphasizes the large contribution of wildfires to the PM2.5 emissions for the same provinces. Canadian wildfires represented 65% and 52% of national PM2.5 and BC, respectively. Collaboration with Andreas Stohl from the Norwegian Institute for Air Research (NILU) initiated the integration of black carbon sources in the Lagrangian dispersion model FLEXPART. Preliminary simulations were able to reproduce some of the episodes detected at Fraserdale, a remote sampling site located in the eastern boreal forest [Sharma et al., 2008]. More extensive work on PM dispersion modelling is presently being performed.

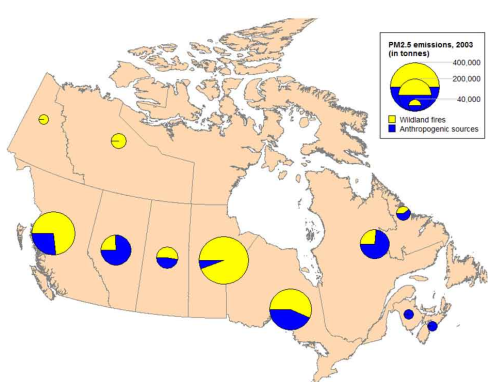

Figure 2. Provincial PM2.5 wildfire emissions (yellow) compared to anthropogenic emissions without open sources (blue).

Emissions for more recent years (2005-2008) are currently under development. In addition, we plan to extend the database back to 1990; we note that 1995 and 1994 have the second and third largest annual areas burned in recent history [Stocks et al., 2003]. Annual greenhouse gas emissions will be routinely compared to anthropogenic numbers that Environment Canada has published every year since 1990 for all provinces and territories. This extended emissions database will also permit analysis of measurements of atmospheric pollutants at monitoring sites during the 1990s, and will allow us to detect and quantify the influence of forest fires.

Wildfire Contributions to Greenhouse Gas Emissions

In 2002, Quebec fires contributed 21% and 3% of the annual provincial and national GHG emissions, respectively. In 2003, wildfires emitted 9% of Canada's annual GHG. In 2004, forest fires in the Yukon were responsible for almost all the GHG released in that territory and represented 10% of the national emissions.

Integrating Wildfire Smoke into Environment Canada's Future Air Quality Forecasting Framework

Numerous studies have pointed out that climate change will significantly increase forest fire danger levels, particularly in west-central Canada. Overall, the consequences would be the occurrence of larger fires, a significant intensification of the emissions, and more smoke episodes in populated areas.

Integrating wildfires into the air quality forecasting framework could be advantageous to fire management agencies by supporting better response to forest fires and smoke events. An agile and comprehensive system would not only improve the ability to anticipate major fire events, fire development as well as smoke trajectories and concentrations, but would also allow accurate deployment of suppression crews. Assessment of the effects downwind smoke might have could play a significant role in planning for evacuation of threatened communities, towns or larger urban areas. It could also guide the choice of suppression tactics: for example, whether to ignite another fire to stop or steer a major fire, where to fight the fire or whether to fight it at all. Estimates of smoke plume heights could also be useful to air traffic controllers.

Forecasting wildfire smoke consists of accurately modelling the extent and composition of smoke plumes in real time across the country and predicting both emissions and atmospheric concentrations one to three days in advance. A future system based on a dynamic emission model could calculate wildfire growth and air pollutant emissions at high geographical and temporal resolutions as shown by Lavoué et al. [2005]. This dynamic model would utilize the Canadian FBP System to calculate hourly fuel consumption and rate of spread for individual fires based on the meteorological conditions forecast by GEM. The fire polygon evolution would be predicted with an elliptical wavelet propagation algorithm. The model would take into account variability in the relative proportions of both flaming and smouldering combustion phases during fire propagation. It would estimate convection column heights from the energy released at the different fire line sections. To start the growing process, initial fire perimeters would be defined from the cluster analysis of fire pixels or hotspots provided by remote sensing, such as MODIS/Aqua & Terra [Anderson, 2008]. Predicted fire polygons could then be compared with burned area surveys carried out by fire agencies for large wildfires monitored in their jurisdictions, since satellite detection is known to be significantly limited in case of cloud cover or heavy smoke.

Future efforts could work in conjunction with the bottom-up approach, using the numerous chemical species and aerosol observations available from satellites (e.g., MOPITT, SCIAMACHY). With this information, models could be validated and the quality of forecasts enhanced. Ground-based (REALM network) and airborne (CALIPSO) lidars could also be employed to adjust plume altitudes and vertical profiles [Duck et al., 2007]. §

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The Canadian Smoke Newsletter

Fall 2008

A newsletter dealing with smoke-related issues relevant to Canada

Revisiting the 1950 Great Smoke Pall

Robert Field, Department of Physics, University of Toronto

Much has been made of recent smoke events in Canada, from the 2001 Chisholm fumigation of Edmonton[1], to the 2002 transport of smoke from Quebec to the eastern US[2,3]. Are there historical precedents for these episodes? Has Canada's boreal forest always been so generous in exporting its smoke?

Witness the "Great Smoke Pall" of September 1950. After a dry summer in northern British Columbia and Alberta, there was an outbreak of fires in mid-September. The biggest of these, the Chinchaga[4], burned 1.4 Mha, making it possibly the biggest fire in North America's recorded history.

The fire took a major run on September 22nd, first sending its smoke northward. The plume was first observed over Ennadai Lake, in what is now Nunavut at 1400 UTC on Sept. 24. Rather than continue along its northeastward path, the plume got caught between a low over Quebec and a ridge extending out from the American Midwest (Figure 1), and was redirected southeastward.

Now on a southeastern course, the smoke aloft was subsequently observed in the Northern Ontario town of Nakina at 1330 UTC, and later in the afternoon, widely across southern Ontario (Figure 2). The pall created a 3-hour blackout in Sarnia[5], and the appearance of dusk at mid-afternoon in Guelph[6]. In Toronto, indoor lights, street lights and automobile headlights were turned on to navigate through the darkness, with city police facing a deluge of calls from concerned citizens[6]. Across the city, the increased power demands added 200,000 kWh to the city's power consumption[5]. Cows had to be milked earlier in the day[6], and the pioneering astronomer Helen Hogg noted that "the darkness was so marked at 3:30 in the afternoon that [I] observed a group of six wild ducks going to sleep quietly in the middle of a pond, with their heads nodding or tucked under their wings."[7] The smoke persisted through the evening, but, on a more positive note, the insulating effects of the night-time smoke layer was thought

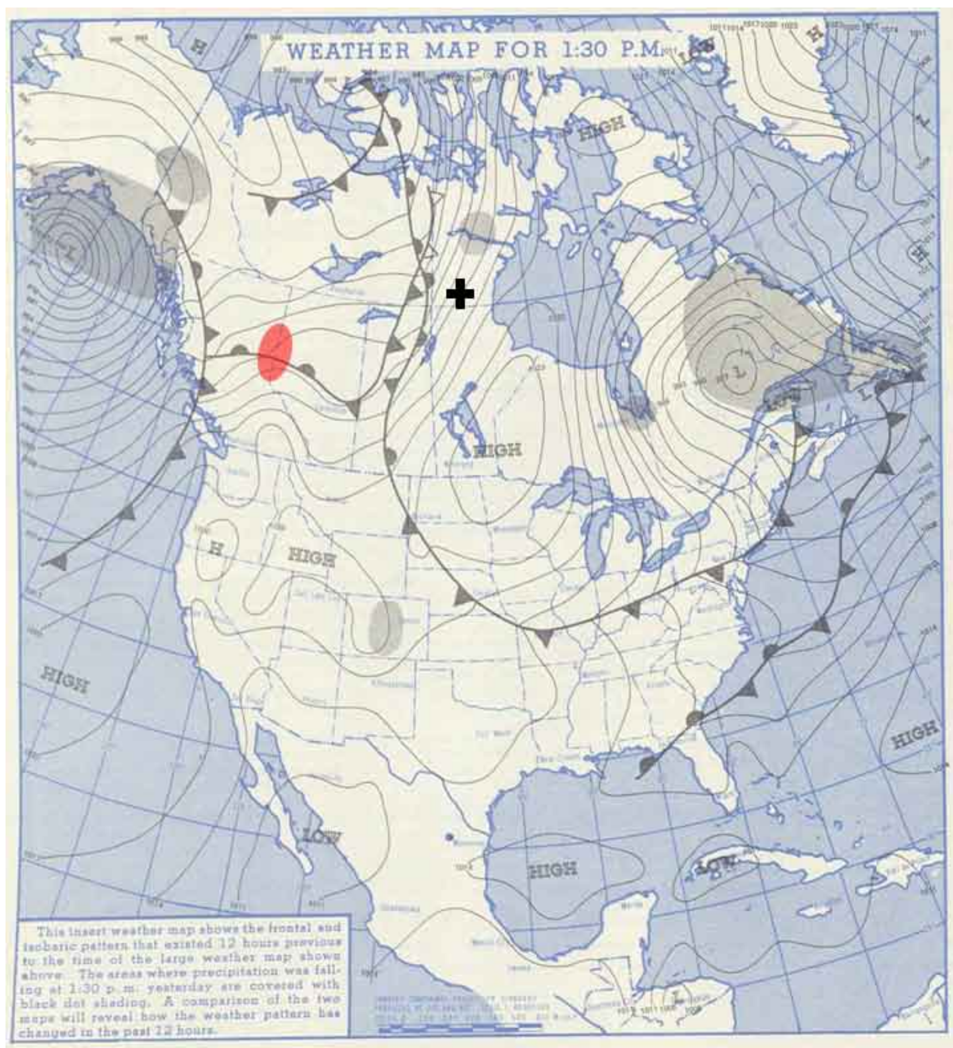

Figure 1. Surface map for 13:30, EST, September 23rd. The red shaded area indicates the burning region. The '+' indicates the location of the first smoke plume observation, Ennadai Lake, Nunavut. Retrieved from http://docs.lib.noaa.gov/rescue/dwm/data_rescue_daily_weather_maps.html.

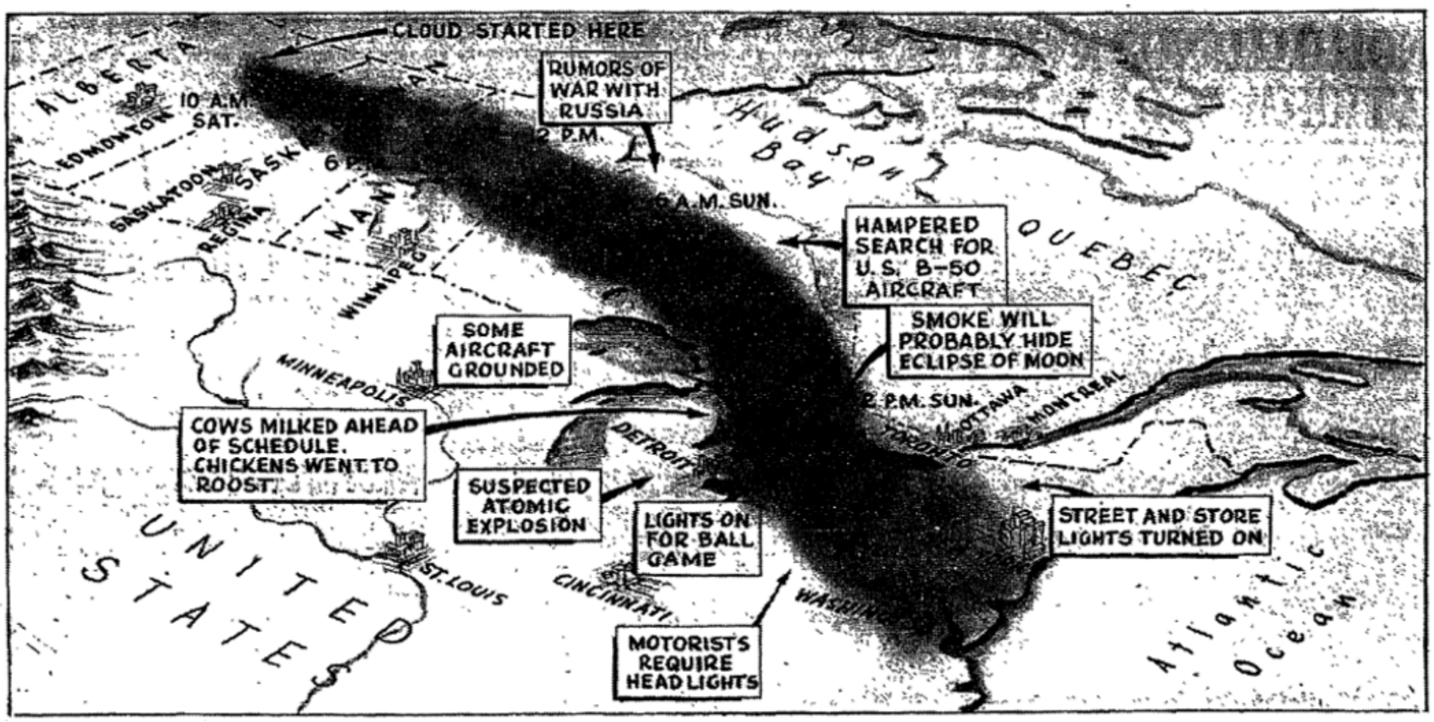

Figure 2. An initial estimate of the smoke plume from the Toronto Star on September 25th. The original caption read "Train of events that followed movement of smoke pall, from northern Alberta".

to have delayed the expected frost[8].

The smoke also disrupted aircraft flights over much of Ontario, with pilots from Sault Ste. Marie to London flying through midnight-like conditions in the brown cloud, while in northern Ontario, an RCAF search for a downed US bomber had to be postponed due to the smoke layer. Earlier, to explain the midday darkness, Northern Ontarians invoked the specter of a nuclear strike; residents of Kapuskasing had thought the search planes had been sent out to combat a Russian invasion[6]! Along with nuclear attack, the smoke cloud was attributed variously to[5-7]: the arrival of doomsday, alien invasion, "a supernatural power angry with the world for tampering with daylight saving time", or, less ominously, local fires in the city.

From Ontario, the smoke continued into Ohio, New York and Pennsylvania. In fact, as it crossed the border, the lights on the Peace Bridge from Ft. Erie, ON, to Buffalo, NY, had to be turned on, as did stadium lights for afternoon baseball games in Cleveland, Pittsburgh and New York City[9]. As in Ontario, the effects on livestock were felt in the US. The New York Times reported that, in Watts Flatts NY, "Mrs. Dora Gesaman announced gravely that at 4 PM, when the overcast lifted, her rooster crowed as if it were dawn and the chickens left the roost under the impression that a new day had arrived." [9]

To document this remarkable event, the great US meteorologist Harry Wexler commissioned a survey of smoke observations across the US, showing that the plume reached as far south as Florida (Figure 3). Over the eastern US, the plume appeared to have split in two, with one part becoming entrained in stagnant, anticyclonic circulation over the southeastern US until September 29[10], creating widespread discoloration.

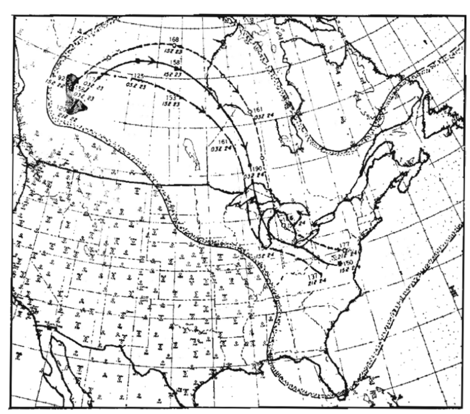

Figure 3. Extent of smoke, based on a special survey of weather stations[10] commissioned by Harry Wexler.

Wexler also estimated that the reflection and absorption of sunlight by the smoke reduced surface temperatures over Washington by up to 4 C°. Amazingly, there were no reports across North America of poor air quality at the surface. Whereas a surface inversion normally traps pollution, in this case, a dome of cold polar air had protected the cities below from the thick smoke above[11].

The other segment of the plume had advected northeastward, and was reported in Newfoundland on September 25th. From that point on, monitoring of the plume rested with the Europeans[12]. A mauve tint to the sun was observed 150 km off the southern tip of Greenland from the S.S. Manchester Progress on September 25th, which was followed by direct aircraft observation on the 26th. On September 27th over Scotland, an RAF reconnaissance plane flown by F/Lt. West Jones was sent from Leuchars, near Dundee, and a pronounced cloud of brown haze was encountered at 12 km. Early the following morning, a pilot over Cambridge reported the smell of burnt paper at the same height. Aircraft reports of the plume over North America were at much lower heights. The reason for this difference in height remains unclear, but two strong possibilities are frontal uplift over the Atlantic, or changes in smoke injection heights during different phases of the fire.

The plume was widely noticed across western and southern Europe, but by this point not as a thick brown cloud. Over the continent, the smoke was reported widely in the form of a blue sun during the day and blue moon at night. There were reports of the blue sun and moon as far east as Poland[13], and as far south as Malta[12]. But what of the plume after this? There are no known reports of the plume in Russia or East Asia, although several days after the smoke event in Toronto, the Globe and Mail speculated, after learning of the observations in Europe, that the smoke “might encircle the world”[8]. There was, however, a lone observation of smoke over the Aleutian Islands in early October, which was linked to the smoke pall[14]. Although exceptional, recent episodes of such circumpolar transport have been well-documented, using modern surface and satellite instruments. The smoke from the 2001 Chisholm fire was detected, after circumpolar transport, in Mauna Loa, Hawaii, and Boulder, Colorado, and in fact lingered in the lower stratosphere for 3 months[15].

We are currently conducting simulations of the fire behaviour and smoke transport to better understand this remarkable event. §

Robert Field is a PhD student in the Department of Physics at the University of Toronto, working under the supervision of Prof. Kent Moore. This work was initiated by Dr. Gerald Holdsworth of the Arctic Institute of North America, and is being carried out in collaboration with Cordy Tymstra of the Alberta Department of Sustainable Resource Development.

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Research Notes and Papers of Interest

A Method to Derive Smoke Emission Rates From MODIS Fire Radiative Energy Measurements

by Charles Ichoku and Yoram J. Kaufman, IEEE transactions on Geoscience and Remote Sensing, Vol 43, No. 11, November 2005

The rate at which a fire releases energy is determined by the rate at which biomass is consumed, which is a function of area burned, biomass density, above-ground fraction and combustion efficiency. Field and laboratory measurements in other studies show the fire radiative energy release (R_{fre}) and mass of dry biomass consumed is in fact a linear one. Assuming that the emission of a particular species (X) is a fixed proportion of dry biomass burned, then the mass of the emitted species can be derived directly from R_{fre} using the equation $M_x = C_e * R_{fre}$ where C_e is a fire radiative energy based emission coefficient.

The MODIS instruments on the Terra and Aqua satellites measure rate of fire radiative energy release in the 3.96 micron channel. These instruments are able to cope with R_{fre} values from 10 to 1700 mW per pixel at 1 km resolution at nadir. In addition, MODIS also measures aerosol optical thickness (AOT) at various wavelengths at 10-km resolution at nadir. R_{fre} and AOT data were combined with wind data from NCEP/NCAR reanalyses for 17 regions around the world to assess smoke emission rates for the year 2002. Plotting R_{fre} versus smoke emissions derived from AOT measurements showed high correlations for some regions, and poor correlations for others. In some cases, subregions showed markedly different correlations than the enclosing parent region. Possible sources of error include the accuracy of MODIS AOT measurements, the conversion of AOT to aerosol mass density, accuracy of winds, accuracy of smoke plume heights, heterogeneity of regional land and vegetation characteristics, and the use of R_{fre} snapshots at a single point in time vs. smoke mass calculations which represented cumulative emissions ending at the time of measurement. §

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

Canadian Smoke Newsletter Author Guidelines

This informal newsletter was produced by the Air Quality section of Prairie and Northern region, Environment Canada, on behalf of the smoke forecasting community. If you wish to be on the email list for future issues or if you want to be taken off the list, please send a note to *al.pankratz@ec.gc.ca*. You can use the same email address if you want to contribute articles, news items, comments or suggestions.

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- 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.
- You are writing for a target audience composed of a mixture of professionals in government, industry and academia, all of whom are involved with smoke and smoke issues. Both descriptive and technical articles are welcome.
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