The BlueSky Eastern Canada Wildfire Smoke Forecasting System

Background

In a typical year Canada experiences around 8,000 wildfires and the resulting smoke can travel hundreds of kilometers and impact the lives of millions of people. Wildfire smoke is comprised of a mixture of gases and particles that can cause eye and respiratory tract irritation as well as more serious issues such as reduced lung function, bronchitis, exacerbation of asthma, and premature death (California Dept of Health, 2008). The smallest particles (with sizes less than 2.5 microns, PM$_{2.5}$) can be inhaled deep into the lungs and are of principal concern for the relatively short exposures associated with wildfire smoke events. Exposure to PM$_{2.5}$ is linked to an increased risk of mortality and aggravation of pre-existing respiratory and cardiovascular disease. See Naeher et al. (2007) for a list of smoke constituents and their associated health effects.

The National Workshop on Smoke Forecasting in Edmonton (Workshop, 2007) identified the need for an operational wildfire smoke forecasting system (SFS) in Canada. Such a system would be a useful tool for weather forecasters, health authorities, researchers, government regulatory agencies and the public. For example, it would provide weather forecasters and environmental agencies with information to respond to public and media interest about the expected duration and intensity of the smoke event. Health authorities would have advance warning about potential exposure to smoke in order to inform evacuation decisions, and the issuance of public health alerts and messages to minimize exposure. In addition, it would provide health researchers with information about smoke exposure in populated areas where there are no air quality measurements, in order to study the health effects of smoke.

Discussions following the Edmonton Workshop led to the proposal of a pilot project that would apply an existing U.S. software framework (called “BlueSky”) in order to provide smoke forecasts to British Columbia (B.C.) and Alberta. In subsequent years this pilot would eventually expand to cover all of Western Canada and in 2013 an SFS for Eastern Canada was created.

Multi-Agency Involvement

Due to the multi-disciplinary nature of the project, in 2008 a multi-agency Steering Group was formed consisting of an informal partnership between provincial, federal agencies, academia and the U.S. Forest Service. Over the lifetime of the project, partner agencies contributed funds, in-kind services and direction. In the early years the project was lead and funded by the B.C. Ministry of Environment and the Alberta Department of Environment and Sustainable Resource Development. In 2013 the Eastern Canada BlueSky was created with the support from the Ontario Ministry of Natural Resources. More recently the project received a grant from the Canadian Safety and Security Program, a federal program led by the Defence Research and Development Canada’s Centre for Security Science.

The multi-agency model continues to be critical to the success of the project given that forecasting smoke from wildfires involves a diverse expertise from the field of meteorology, fire behavior, remote sensing, health, public communication and computer technology.

Eastern Canada BlueSky System

“BlueSky” is a software framework developed by the U.S. Forest Service (Larkin et al. 2008) that consists for data and models of fuel consumption, emissions, fire, weather, and dispersion linked into a single system which produces forecasts of hourly ground-level concentrations of PM$_{2.5}$ from wildfires up to 48 hours into the future. The U.S. BlueSky SFS provides smoke forecasts in various areas throughout the continental U.S.
There are many advantages associated with adapting an existing system for Canada rather than creating a new one such as: applying technology already in operational use, benefitting from upgrades and expertise through the efforts of the U.S. BlueSky team, and the ability to swap in Canadian components such as emissions and meteorological model output.

Figure 1 shows the structure and major components of the system. These are described in the following sections.

**Hourly Meteorological Forecast:**
Weather Forecast Model for Eastern Canada: University of British Columbia in Vancouver, B.C.

**Wildfire Location and Fuel Consumption:**
Canadian Wildland Fire Information System: Natural Resources Canada, Northern Forestry Research Centre in Edmonton, Alberta

*Transport and Dispersion*
BlueSky System Processing:
University of British Columbia

*Web Available Output:*
Animations of hourly smoke plume trajectories, ground-level concentrations of PM$_{2.5}$ for Eastern Canada

**Figure 1.** Structure and Components of the Eastern Canada BlueSky Smoke Forecasting System

### Hourly Meteorological Forecast

The BlueSky system requires an advanced weather forecast model to predict meteorology every hour for up to two-days into the future. The Department of Earth and Ocean Sciences at the University of British Columbia (UBC) in Vancouver, B.C., Canada runs weather forecast models (see [http://weather.eos.ubc.ca/wxfcst/](http://weather.eos.ubc.ca/wxfcst/)) including a model called MM5 (Dudhia, 1993) and its successor WRF (Michalakes et al, 2001). During the first three years of the Western Canada SFS operation, the MM5 model provided the weather forecast at high spatial resolution over B.C. and Alberta (every 4 km in order to account for the effects of rugged terrain), and every 12 km for the rest of Western Canada. In 2013 a switch was made to the more advanced, WRF model.

For Eastern Canada, the WRF model spatial resolution is currently 36 km, with a finer resolution is planned for the summer of 2014.

### Wildfire Location and Emissions

The BlueSky system requires real-time wildfire location and fuel consumption estimates in order to locate the fires and determine the amount of smoke emissions. This information is supplied by the Canadian Wildland Fire Information System (CWFIS) operated by the Canadian Northern Forestry Centre in Edmonton, Alberta. The CWFIS includes the Fire Monitoring, Mapping, and Modelling (FireM3) system and National Forest Inventory data.
FireM3 uses satellite-based hotspot detection along with algorithms to estimate fire size for any detected wildfire. Fuel consumption estimates suitable for the transport and dispersion part of the BlueSky system are based on National Forest Inventory data. The CWFIS data is accessed twice daily via a data link to the BlueSky server residing at UBC.

An additional emissions processor, called SmartFire2 (SF2), was added to the system in 2012. Large wildfire complexes can have several hotspots, so SF2 combines the multiple adjacent fires into a single emission source using a clumping algorithm. During intense wildfire periods, this reduces the computational load when there are hundreds of fires to process. In addition, SF2 has the ability to process wildfire observational reports provided by agencies involved in fire suppression. These reports can include wildfire location, burn area, and other characteristics. SF2 combines these observations with the satellite derived information to create a more complete characterization of the wildfire. For example, although a wildfire may escape satellite detection due to thick cloud, it could still be reported in the daily fire reports so the smoke from this previously un-detected wildfire can now be accounted for in the forecast.

Smoke Transport and Dispersion

Given both the emissions and the meteorological conditions, a transport and dispersion model, called HYSPLIT, calculates the spatial extent of the smoke plume(s) and the corresponding PM$_{2.5}$ concentrations every hour. HYSPLIT is a model developed by the U.S. National Atmospheric and Oceanic Administration that simulates plume behavior over large distances for variety of sources that can range in size from volcanoes to industrial stacks. Wildfire smoke plumes are modeled as a series of puffs that are tracked individually as they move and grow in response to changing meteorology. The most recent version of the BlueSky system uses a parallel processing version of HYSPLIT in order to reduce the computational load of tracking the puffs from hundreds of fires over the forecast period.

Finally, earlier versions of the system had a rudimentary treatment of carry-over smoke i.e. the smoke left-over from the previous forecast carried into the current forecast. The most recent version of BlueSky has a more complete treatment of this behavior, and should result in better predictions especially for periods of changing wind directions and long smoke transport distances.

Smoke Forecasts: Availability

Given the wide interest and need for smoke forecasts from a variety of interests, it is important to provide forecasts that are current, publically available and in a useable format.

Given this goal, daily forecasts showing visual animations of smoke impacted areas and the corresponding PM$_{2.5}$ concentrations every hour up to 2 days into the future are available from a B.C. Ministry of Environment website (www.bcairquality.ca). This involves daily downloads of the BlueSky system output files from UBC and web posting them in JPEG and KMZ formats. The JPEG format is the most versatile as it does not require any specialized software to display the results. The KMZ format allows users to view smoke forecast animations in Google Earth. This provides additional functionality such as the inclusion of data layers (roads, cities) and magnification of select areas. Figure 2 shows an example forecast map from the Eastern Canada BlueSky webpage (www.bcairquality.ca/bluesky/east).

An Operational Smoke Forecasting System

The components of the Eastern Canada BlueSky SFS were successfully installed in early 2013 and in mid-June the system was run operational test mode to assess its behavior and
ability to handle large numbers of wildfires. These tests showed that the source, meteorology, transport, dispersion and output display are properly linked and producing results consistent with each of their respective functions. In addition, comparisons of the forecast smoke patterns were made with actual smoke distribution as determined by satellite imagery for a few wildfire intense periods. These preliminary comparisons indicated that there was consistency between the forecast smoke patterns and the actual smoke distribution as provided by satellite.

![Figure 2 Eastern Canada Forecast Output (forecast area shown in grey shade)](www.bcairquality.ca/bluesky/east/)

**Evaluation and Forecast Uncertainties**

A systematic forecast performance assessment of the Eastern Canada SFS has not yet been conducted as it only operated a few months in 2013. However evaluations conducted on the Western Canada system (Klikach et al. (2012), Yao (2013)) provide some indication of the overall BlueSky system performance. These studies involve comparisons of the forecasts to satellite imagery and hourly PM$_{2.5}$ concentrations measured at air quality stations in B.C. and Alberta.

Performance evaluation involves comparisons to observations based on three indicators: the smoke location, the timing of a smoke event and the PM$_{2.5}$ concentrations. Achieving good agreement for all three criteria is extremely challenging. For example, even though the smoke impact area may be forecasted perfectly, the PM$_{2.5}$ concentrations may not be cor-
rect. Conversely the predicted PM$_{2.5}$ concentrations may be correct, but the forecast timing of a smoke event could be off by several hours.

Qualitative comparisons with satellite imagery for intense wildfire periods indicate that the forecasts show a general consistency with the large scale, observed smoke patterns although the forecast patterns are not as expansive as what was observed. The quantitative evaluation studies for the Western Canada SFS using observed hourly PM$_{2.5}$ concentration measurements at air quality stations indicate that the system can have large misses. The latter is not surprising given the uncertainties associated with the inputs and models for weather forecasts, emissions characterization and transport and dispersion. Investigation is currently underway that will help identify periods of good performance and periods where improvements are needed. For example, Klikach et al. (2012) found that the carry-over of smoke into the next forecast should improve model performance. This feature is now included in the latest version of the system.

These evaluation studies indicate there is more certainty in the forecast plume impact zones that depict relative measures of impact, rather than absolute PM$_{2.5}$ concentrations. They also point to the need to further improve the source characterization (notably plume rise and emissions estimates) and the transport and dispersion (inclusion of carry over smoke). Further qualitative and quantitative evaluations of the performance of both the Western and Eastern systems are underway and are critical to the further development improvement of the forecasts.

**Summary**

The Eastern Canada SFS is a Canadian version of the U.S. Forest Service, BlueSky framework and is anticipated to inform a wide variety of interests impacted by wildfire smoke. It has benefitted from the development and experience of the Western Canada SFS, which has operated since 2010. A multi-agency workgroup, representing a wide variety of expertise, provides direction and support to the project and is critical to its success.

Due to the research nature of this project, the uncertainties associated with modelling such a complex process and need for further evaluation and development, the forecasts are considered “experimental”. However, BlueSky represents a systematic application of advanced scientific tools and input data to this complex process. With further evaluation, enhancements and user experience, the system will find greater use as a tool to inform a wide range of interests that are impacted by wildfire smoke.

**Acknowledgements**

The following individuals and agencies have been critical to the creation, development and support of both the Eastern and Western versions of this system. G. Okrainetz, C. Jenkins, L. Huang, W. Mohns (B.C. Ministry of Environment); E. Meyer, L. Gawalko (B.C. Ministry of Forests, Lands and Resource Operations); K. Anderson, P. Englefield (Natural Resources Canada); R. Stull, R. Schigas, G. Hicks, M. Brauer, S. Henderson (University of B.C.); D. Lyder, L. Cheng, D. Schroeder (Alberta Dept of Environment and Sustainable Resource Development); B. Cole, M. Rice, N. Galambos (Ontario Ministry of Natural Resources); K. McCullum (Saskatchewan Ministry of the Environment) A. Pankratz, R. Vingarzan, (Environment Canada); B. Crumb (Manitoba Health); S. Larkin, S. O’Neill (U.S. Forest Service); S. Raffuse, K. Craig, J. DeWinter (Sonoma Technology Inc); Elizabeth Henry (B.C. Clean Air Research Fund/Ministry of Environment); Canadian Safety and Security Program (Defence Research and Development Canada’s Centre for Security Science).
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References


