The BlueSky Western 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 lead to the proposal of a pilot project that would apply an existing U.S. system (called “BlueSky”) in order to provide smoke forecasts to British Columbia (B.C.) and Alberta.

Multi-Agency Involvement

Due to the multi-disciplinary nature of the project, in 2008 a multi-agency Steering Group was created consisting of an informal partnership between provincial, federal agencies, academia and the U.S. Forest Service. In the early years the Western Canada BlueSky 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. In 2013, the project also received a 3 year 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, database management, public communication and computer technology.

Western Canada BlueSky System

“BlueSky” is a software framework developed by the U.S. Forest Service (Larkin et al. 2008) that consists of data and models of fuel consumption, emissions, fire, weather, and dispersion. These are linked together into a single system that 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. (www.getbluesky.org/home.cfm)

There are many advantages associated with adapting an existing system rather than creating a new one: 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.

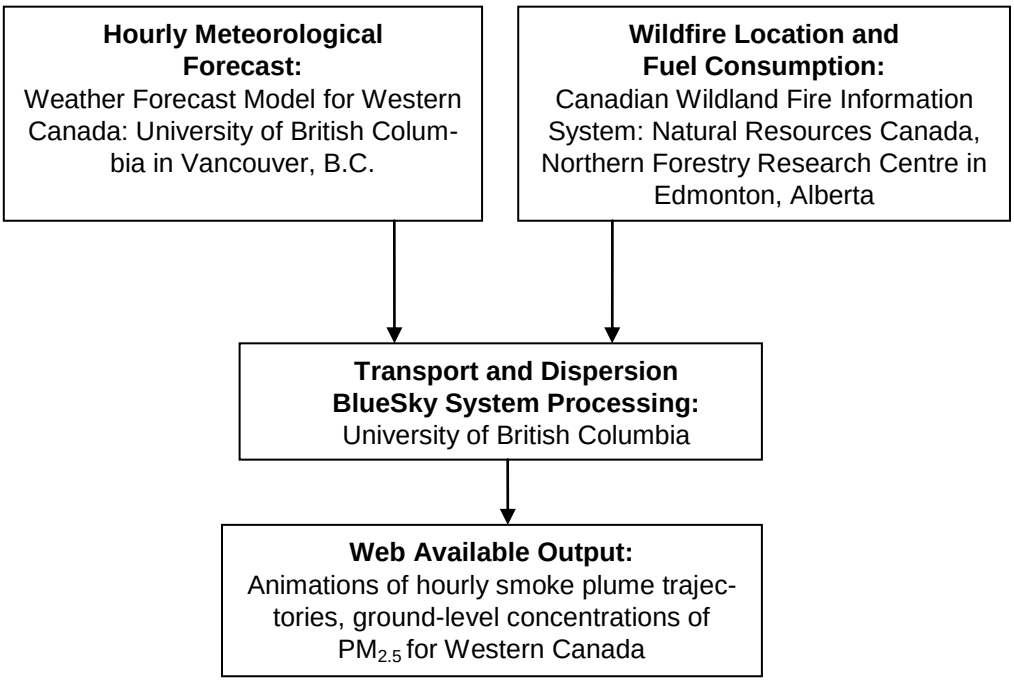

Figure 1. Structure and Components of the Western Canada BlueSky Smoke Forecasting System

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/) including a model called MM5 (Dudhia, 1993) and its successor WRF (Michalakes et al, 2001) . During the first three years of operation, the MM5 model provided the weather forecast for the BlueSky system at a 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.

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 (http://cwfis.cfs.nrcan.gc.ca/). FireM3 uses satellite-based hotspot detection along with algorithms to estimate fire size for any detected wildfire. Fuel consumption estimates, required

for the smoke dispersion predictions, are based on National Forest Inventory data. The CWFIS data is accessed twice daily via a data link to the Western Canada 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 processs. In addition, SF2 has the ability to include wildfire observational reports provided by wildfire suppression agencies. The reports can include wildfire location, burn area, and other characteristics. SF2 combines these observations with the satellite derived information in order 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 SFS 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 usable format.

Given this goal, twice-daily forecasts showing animations of smoke plumes 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 twice-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 the user to view smoke forecast animations in Google Earth. This provides users with additional functionality such as the inclusion of more data layers (roads, cities) and magnification of select areas. Figure 2 shows an example of the forecast output map available from the Western Canada BlueSky SFS webpage (www.bcairquality.ca/bluesky/west).

An Operational Smoke Forecasting System

The components of the Western Canada BlueSky SFS were successfully installed on a new server and the system produced its first test forecasts in late 2009. The system was stress-tested by running simulations for periods of extreme fire activity in B.C. and evaluated

by comparing forecast output to actual plume locations (as derived by satellite imagery). The initial tests showed that the system is able to handle large data volume situations and produce results that show the source, meteorology, transport, dispersion and output display are properly linked and producing results consistent with each of their respective functions. These tests provided confidence in the systems ability to process volumes of data correctly, and to produce reasonable estimates of plume impacted areas.

The system began operation as a pilot during the summer of 2010 and produced daily forecasts for B.C. and Alberta. In August of that year (a period of intense wildfire activity in B.C.), the Western Canada BlueSky website received over 60,000 hits – confirming the high interest and need for this tool. The success of the pilot led to more contributions from the partner agencies, which in turn resulted in further improvements to the system as well as its expansion to cover all of Western Canada (shown in the grey shade areas in Figure 2).

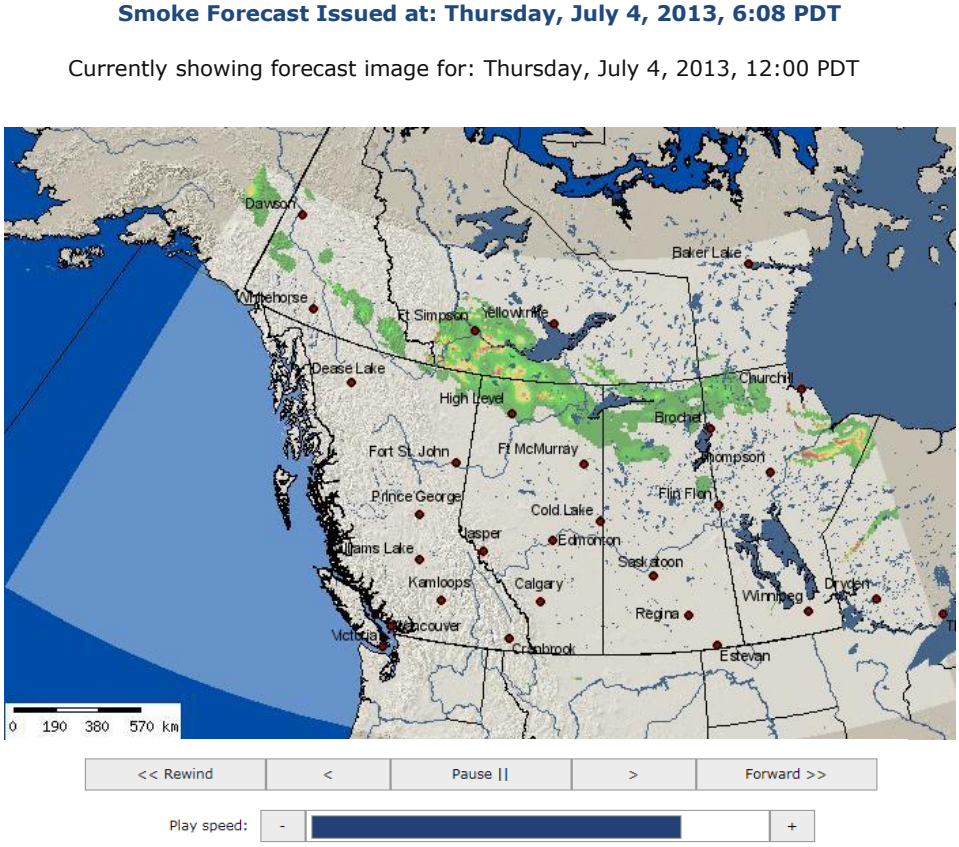

Figure 2 Western Canada Forecast Output (forecast area shown in grey shade)

Evaluation and Forecast Uncertainties

The forecast performance of the system has been evaluated both qualitatively and quantitatively (Klikach et al. (2012), Yao et al. (2013)) using both satellite imagery and hourly $PM_{2.5}$ concentrations measured at air quality stations in B.C. and Alberta. Evaluation involves comparisons to observations based on three performance 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 correct. 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 indicate that the forecasts show a general consistency with the large scale, observed smoke patterns during intense wildfire periods, while errors occur when predicting the smaller geographic scale details of the smoke distribution. The quantitative evaluation studies using observed $PM_{2.5}$ concentration measurements at air quality stations indicate that the predictions can have large misses. This 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 the system are underway and are critical to system developments that will improve the forecasts.

Summary

The Western Canada SFS is a Canadian implementation of the U.S. Forest Service, BlueSky framework and benefits a wide variety of interests impacted by wildfire smoke. A multi-agency workgroup, representing a variety of expertise, provides direction and support to the project and has been critical to its success over the past five years of operation. The experience of the previous fire seasons indicates the high interest and need for this information – which has lead to continued support for its operation and improvements.

Due to the research nature of this project, given 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.

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