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# THE BLUESKY WESTERN CANADA WILDFIRE SMOKE FORECASTING SYSTEM

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## 1. INTRODUCTION

Smoke impacts from wildland fires are a growing concern due to increasing fire season severity, the public's dwindling tolerance of smoke, more rigorous air quality regulation, and fire's role in climate change. In recent years, real-time smoke prediction systems, such as the operational National Weather Service Smoke Forecasting System (Rolph et al., 2009) and the experimental Sonoma Technology, Inc. (STI) and USDA Forest Service (USFS) BlueSky Gateway system (Craig et al., 2007; Strand et al., 2012), have been developed in the United States to inform decision makers and the public about potential smoke impacts from wildfires. These systems link fire detection and information systems and fire emissions models to traditional meteorological and air quality models to provide forecasts of smoke plume footprints and ground-level $PM_{2.5}$ concentrations due to fires. Both systems directly benefit from advances in fuel consumption and fire emissions science incorporated into the USFS BlueSky Smoke Modeling Framework (BlueSky Framework) (Larkin et al., 2009). BlueSky Gateway also benefits from fire information made available through the Satellite Mapping Automatic Reanalysis Tool for Fire Incident Reconciliation (SmartFire) system (Raffuse et al., 2006; 2011).

In Canada, the need has also grown for an integrated, operational smoke prediction system to inform weather forecasters, health authorities, researchers, regulatory agencies, and all levels of government and the public about potential smoke impacts. This need was formalized at the 2007 National Workshop on Smoke Forecasting in Edmonton (Environment Canada et al., 2007). Discussions following this workshop led to the development of a pilot project in 2008 to develop an operational smoke forecasting capability for British Columbia and Alberta. An informal steering group (Table 1), consisting of provincial agencies in British Columbia and Alberta, the University of British Columbia (UBC), USFS, Environment Canada, and Natural Resources Canada, provides overall direction to the pilot project. Partner agencies have contributed funds to the pilot project, as well as in-kind services and direction to the overall project design. STI implemented the system and trained technical support staff at UBC.

Table 1. Partners in the Western Canada Smoke Modeling System pilot study steering group.

| Pilot Study Collaborative Partners |
|---|
| B.C. Ministry of Environment |
| B.C. Ministry of Forests, Lands, and Natural Resource Operations |
| University of British Columbia |
| Environment Canada |
| Alberta Department of Environment |
| Alberta Environment Sustainable Resource Management |
| Natural Resources Canada |
| USFS AirFire Team |
| Manitoba Health |

The Western Canada Wildfire Smoke Forecasting System became operational during the 2010 wildfire season, and since then the system has matured and evolved to meet a growing need for smoke prediction capabilities across Canada.

This paper describes the Western Canada Wildfire Smoke Forecasting System and its components, evolution, evaluation, and future.

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## 2. SMOKE FORECASTING SYSTEM

### *2.1 Philosophy*

Rather than creating a new system from scratch, the pilot study steering group elected to build the Western Canada smoke forecasting capability around an existing system, the BlueSky Framework, to leverage tested technology that has been operating elsewhere, and to provide a common system for treating smoke impacts from fires in both the U.S. and in Canada. Also, because of its modular software design, the BlueSky Framework could be customized to use high-resolution meteorological forecasts for western Canada, incorporate fire information systems and science capabilities developed by Natural Resources Canada (Canadian Forest Service), and apply the desired smoke dispersion model.

The BlueSky Framework provides a centralized software system for interconnecting fire science data and models to predict smoke impacts. Through a partnership with the USFS AirFire Team and STI, the BlueSky Framework was made available to the pilot project, extended to incorporate Canadian fire science and data, and implemented into the Western Canada smoke prediction system. The BlueSky Framework was implemented at UBC to be collocated with the large meteorological inputs generated by UBC.

The smoke prediction system integrates several components running at different locations throughout western Canada (Fig. 1) into a unified system for predicting ground-level smoke concentrations and delivering those predictions to end users. These components include (1) meteorological forecasts, (2) wildfire information and fuel consumption estimates, (3) emissions calculations, smoke dispersion predictions, and graphical output generation through the BlueSky Framework, and (4) a product delivery website. These components are described in more detail below.

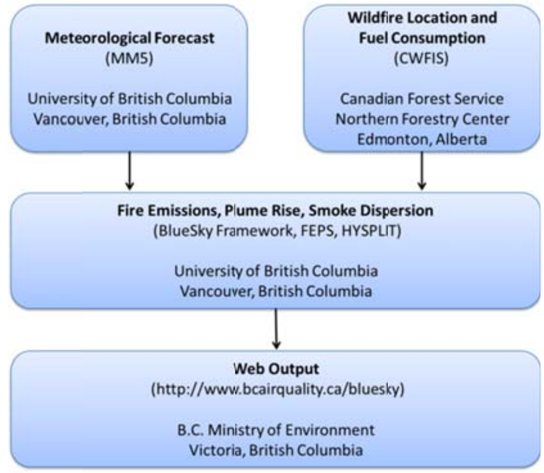


Fig. 1. Overview of the BlueSky Western Canada Smoke Forecasting System

### *2.2 Meteorological Forecasts*

Smoke predictions are driven by meteorological data generated by the Pennsylvania State University/National Center for Atmospheric Research Mesoscale Model, Version 5 (MM5) (Grell et al., 1994). These weather forecasts are generated twice daily in real time by the Department of Earth and Ocean Sciences at UBC (http://weather.eos.ubc.ca/wxfcst) at 12 km spatial resolution on a grid covering much of Canada, and at 4 km spatial resolution on a grid covering British Columbia and Alberta. The BlueSky Framework was modified to accommodate simultaneous nested MM5 grids.

### *2.3 Canadian Wildfire Location and Fuel Consumption*

Canadian forest fuel characteristics can be quite different from those in the U.S., and therefore an important challenge facing the pilot project was incorporating Canadian-based fire data and science into the U.S.-based BlueSky Framework. For the current work, real-time fire location information and fuel consumption estimates are provided by the Canadian Wildland Fire Information System (CWFIS) (http://cwfis.cfs.nrcan.gc.ca). The CWFIS is a fire management and information system developed by the Canadian Forest Service to monitor fire activity and fire danger conditions across Canada. Wildland fire locations are determined using a Moderate Resolution Imaging Spectroradiometer (MODIS) satellite-based hotspot detection algorithm from the Fire Monitoring, Mapping, and

Modeling System (known as Fire M3), while Canada National Forest Inventory data, along with the CWFIS Forest Fire Behavior Prediction System, are used to develop fuel consumption estimates. Additional information on these CWFIS components can be found at http://cwfis.cfs.nrcan.gc.ca/background.

Fire location information and fuel consumption data are acquired in real time from the CWFIS and consolidated by SmartFire version 2 (SF2). Recently added to the smoke prediction system, SF2 reduces redundant fire detections and applies clumping algorithms to consolidate individual CWFIS fire detects. These features improve the accuracy of fire locations and area-burned estimates, provide fire footprint tracking for large wildfire events, and reduce the number of emission points that must be handled by the smoke dispersion model (Fig. 2). Though SF2 currently ingests a single data stream, CWFIS, it can accommodate additional fire information data streams as they become available in the future. Consolidated fire information and fuel consumption information from CWFIS and SF2 are passed into the BlueSky Framework for subsequent processing.

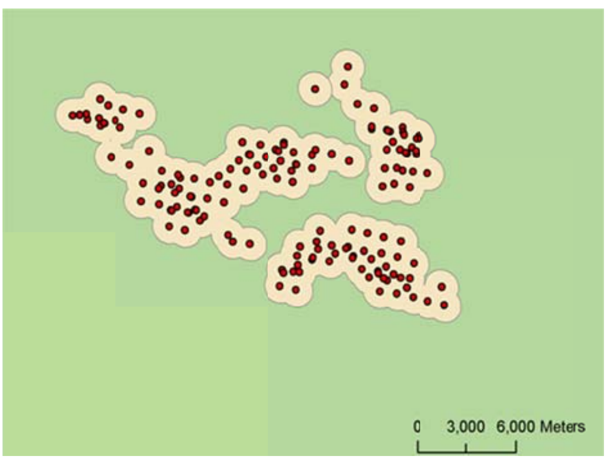


Fig. 2. Sample fire locations and footprint results from SF2 on a cluster of fires in B.C. on August 18, 2010. SF2 consolidated 1,610 individual hotspots into 200 clumps, an 88% reduction in fire locations to be modeled.

### *2.4 BlueSky Framework*

The BlueSky Framework inputs MM5 meteorological data produced by UBC, as well as fire information and fuel consumption data acquired from CWFIS and processed by SF2. The BlueSky Framework then executes a series of models to calculate emission rates, determine plume rise characteristics, predict smoke concentrations, and generate graphics. The BlueSky Framework also contains programs to prepare MM5 data for the dispersion model, so that all operations can be performed in a single execution.

The BlueSky Framework is packaged with numerous options for each modeling sub-component. For the current smoke forecasting system, the BlueSky Framework is configured to calculate emission rates with the Fire Emissions Production Simulator (FEPS) (Anderson et al., 2004), determine plume heights based on the Briggs plume rise methodology as implemented in FEPS, and model smoke dispersion with the Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT) (Draxler and Hess, 1997, 1998) version 4.8. HYSPLIT is configured to model $PM_{2.5}$ transport and diffusion in a full puff mode, with no chemistry.

Smoke forecasts out to 60 hours are generated twice daily, and are initialized at 00 UTC and 12 UTC to coincide with UBC's MM5 forecast cycles. Fire locations and fuel consumption rates from CWFIS are assumed to persist throughout the forecast period (known as a persistence fire growth model). Currently, smoke forecasts are initialized from a clean background state, but initializations from prior smoke forecasts are being considered for the 2013 fire season to model smoke carryover effects.

### *2.5 Website*

Output products are disseminated to the public through the British Columbia air quality website maintained by the British Columbia Ministry of Environment at http://www.bcairquality.ca/bluesky (Fig. 3). The website provides access to an animation of hourly ground-level $PM_{2.5}$ concentrations due to wildfire across much of Canada. The smoke forecast is also made available in Google Earth display format. These graphics, along with the raw modeling inputs and outputs, are archived internally for future evaluation and research.

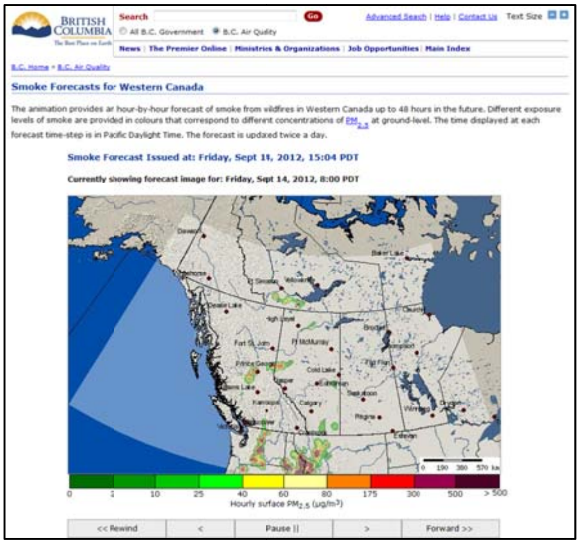


Fig. 3. Screenshot of the British Columbia air quality website showing a ground-level $PM_{2.5}$ prediction from the Western Canada Wildfire Smoke Forecasting System.

## 3. SYSTEM EVALUATION

Since its inception, the Western Canada Wildfire Smoke Forecasting System has undergone both qualitative and quantitative evaluations. These evaluations have revealed system strengths and weaknesses, demonstrated the potential utility of the system for public health protection, and provided direction for system improvements and future work.

Qualitative evaluations have focused on graphical comparisons of model-predicted ground-level $PM_{2.5}$ concentrations against smoke plumes observed from satellite imagery. Evaluations of the August 2009 British Columbia wildfire outbreaks (Craig et al., 2010), the May 2011 Slave Lake, Alberta, fire (Klikach et al., 2012, Fig. 4), and the August 2010 British Columbia fires (Klikach et al. 2012; Figs. 5 and 6) have all shown good qualitative agreement between modeled ground-level $PM_{2.5}$ and satellite imagery. A more refined comparison of modeled smoke-plumes against observed plumes from the National Oceanic and Atmospheric Administration Hazard Mapping System (HMS) during August 2010 by Yao (2012) also suggested reasonable agreement, noting that predicted plumes were generally smaller than the observed plumes.

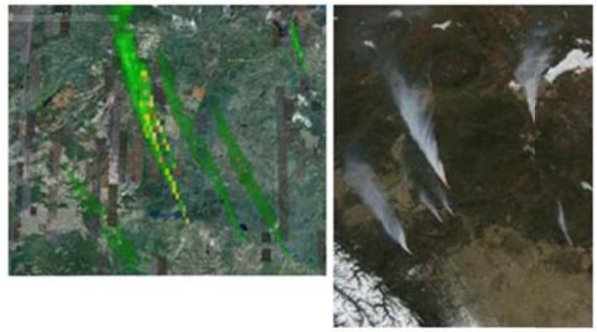

Fig. 4. Predicted ground-level smoke concentrations (left) and MODIS satellite imagery of smoke plumes (right) for the Slave Lake, Alberta, fires on May 15, 2011. From Klikach et al. (2012).

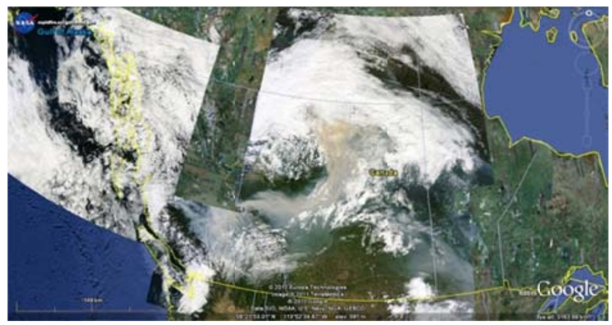

Fig 5. MODIS satellite image for August 19, 2010, superimposed on a Google Earth basemap. Smoke was generated from several large wildfire fire complexes in British Columbia. From Klikach et al. (2012).

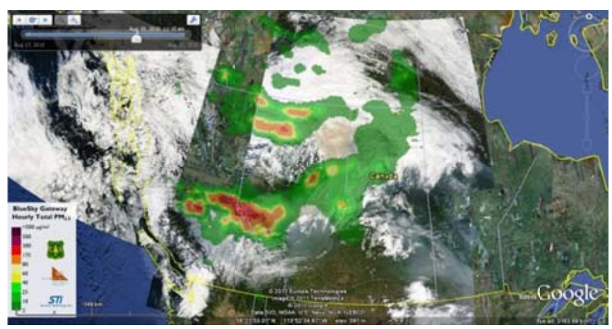

Fig. 6. MODIS satellite image for August 19, 2010, and smoke forecast valid at 1100 PDT superimposed on a Google Earth basemap. From Klikach et al. (2012).

Recently, more extensive quantitative evaluations of the smoke prediction system against monitored $PM_{2.5}$ data across British Columbia and Alberta have been performed. An evaluation of the 2010 fire season by Yao (2012) showed that predicted ground-level $PM_{2.5}$ concentrations in British Columbia coincided with peaks in both observed $PM_{2.5}$ concentration, and dispensation counts for respiratory reliever medication (Fig. 7).

Klikach et al. (2012) performed a rigorous statistical evaluation of forecast performance for the 2010 and 2011 fire seasons against ambient $PM_{2.5}$ data in Alberta. Preliminary results from this evaluation highlighted the importance of retaining sufficient smoke within the modeling system in order to reproduce good estimates of ground-level $PM_{2.5}$ due to forest fire smoke. As a result of this evaluation, the retention of carryover smoke in the prediction system is being considered for the 2013 fire season. Klikach et al. (2012) also examined methods for treating background ambient variability due to non-forest fire $PM_{2.5}$.

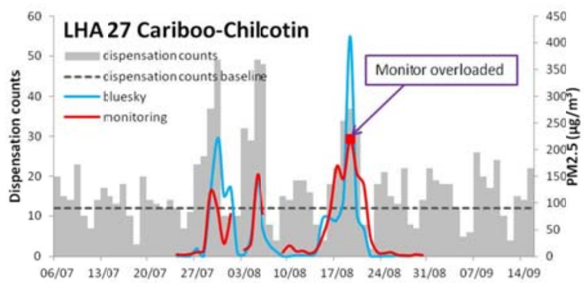


Fig. 7. Monitored (red) and predicted (blue) $PM_{2.5}$ concentrations, and dispensation counts for respiratory medications (grey), in the Cariboo-Chilcotin local health area of British Columbia for July through September of 2010. The dashed line indicates the daily average dispensation count for July, August, and September from 2003 through 2010. From Yao (2012).

## 4. CONCLUSION AND SYSTEM ENHANCEMENTS

Through a multi-agency partnership, an integrated smoke forecasting system has been developed for Western Canada. The partner agencies brought together Canadian and American fire science software, data, and knowledge, as well as funding, in-kind support, and direction for the project. STI implemented the system and trained technical support staff at UBC. The British Columbia air quality website (http://www.bcairquality.ca/bluesky) provides access to hourly ground-level smoke concentration forecasts.

Since becoming operational during the 2010 wildfire season, this forecasting system has undergone both qualitative and quantitative evaluations against satellite imagery, HMS smoke plume analyses, and monitored $PM_{2.5}$ data. These evaluations have shown that the prediction system is functioning properly and is performing reasonably well.

The Western Canada BlueSky Smoke Forecasting system has undergone numerous enhancements since its 2010 inception. These enhancements include

- Domain expansion to include all of Western Canada.
- BlueSky Framework support for nested MM5 modeling grids.
- Addition of SF2 to consolidate CWFIS fire detects and provide flexibility for adding wildfire incident data sources in the future.

Enhancements under consideration for the 2013 fire season include

- Retention of carryover smoke.
- Additional expansion of modeling domains.
- Addition of new wildfire incident data streams through SF2.
- Utilization of parallelized HYSPLIT.

## 5. ACKNOWLEDGMENTS

The Western Canada BlueSky Smoke Forecasting System was made possible with funding, in-kind support, and direction from the following partner agencies:

- B.C. Ministry of Environment
- B.C. Ministry of Forests, Lands, and Natural Resource Operations
- University of British Columbia
- Environment Canada
- Alberta Department of Environment
- Alberta Environment Sustainable Resource Management
- Natural Resources Canada
- USFS AirFire Team
- Manitoba Health

## 7. REFERENCES

Anderson G.K., Sandberg D.V., and Norheim R.A. (2004) Fire Emission Production Simulators (FEPS). User's Guide prepared for the Joint Fire Science Program and the National Fire Plan, January.

Craig K.J., Wheeler N.J.M., Reid S.B., Gilliland E.K., and Sullivan D.C. (2007) Development and operation of national CMAQ-based $PM_{2.5}$ forecast system for fire management. Presented at the *6th Annual CMAS Conference, Chapel Hill, NC, October 1-3*, by Sonoma Technology, Inc., Petaluma, CA (STI-3228).

Craig K.J., DeWinter J., and Raffuse S. (2010) Qualitative analysis of the Western Canada BlueSky Pilot System for August 2009. Technical memorandum prepared for Rachel Mintz, Environment Canada, Edmonton, Alberta, Canada by Sonoma Technology, Inc., Petaluma, CA, STI-909057-3866-TM, April 30.

Draxler R.R. and Hess G.D. (1997) Description of the HYSPLIT 4 modeling system. Technical memorandum by the National Oceanic and Atmospheric Administration, Silver Spring, MD, ERL ARL-224, December 24.

Draxler R.R. and Hess G.D. (1998) An overview of the HYSPLIT_4 modeling system of trajectories, dispersion, and disposition. *Aust. Meteor. Mag.,* **47**, 295-308.

Environment Canada, Alberta Environment, Alberta Sustainable Resource Development, and British Columbia Ministry of Environment (2007) Smoke forecasting workshop 2007 proceedings. *Smoke Forecasting Workshop, Edmonton, Alberta, February 20-21*.

Grell G.A., Dudhia J., and Stauffer D.R. (1994) A description of the fifth-generation Penn State/NCAR mesoscale model (MM5). Prepared by the National Center for Atmospheric Research, Boulder, CO, NCAR Technical Note-398.

Klikach V., Lyder D., Cheng L., Sakiyama S., Hicks G., and Anderson K. (2012) The development and evaluation of a BlueSky Wildfire Smoke Forecasting Framework for Western Canada. Presented at the Air and Waste Management Association Annual Conference, San Antonio, TX, Paper 2012-A-507-AWMA, June 19-22.

Larkin N.K., O'Neill S.M., Solomon R., Raffuse S., Strand T.M., Sullivan D.C., Krull C., Rorig M., Peterson J., and Ferguson S.A. (2009) The BlueSky smoke modeling framework. *Int. J. Wildland Fire,* **18**, 8, 906-920 (STI-3784, doi:10.1071/WF07086).

Raffuse S., Chinkin L., Sullivan D., and Larkin N. (2006) Applications of a GIS-based fire emissions model - or - BlueSky SMARTFIRE. Presentation for the *Third International Fire Ecology & Management Congress, San Diego, CA, November 18,* by Sonoma Technology, Inc. and U.S. Forest Service AirFire Team (STI-3041).

Raffuse S.M., Larkin N.K., Pryden D.A., and Dedecko T.M. (2011) New methods for modeling and monitoring wildfires using multiple data sources: Smartfire v2. Poster presented at the *AGU Fall Meeting, San Francisco, CA, December 9* (STI-4181).

Rolph G.D., Draxler R.R., Stein A.F., Taylor A., Ruminiski M.G., Kondragunta S., Zeng J., Huang H., Manikin G., McQueen J.T., and Davidson P.M. (2009) Description and verification of the NOAA smoke forecasting system: the 2007 fire season *Weather and Forecasting,* **24**, 361-378.

Strand T.M., Larkin N., Craig K.J., Raffuse S., Sullivan D., Solomon R., Rorig M., Wheeler N., and Pryden D. (2012) Analysis of BlueSky Gateway $PM_{2.5}$ predictions during the 2007 southern and 2008 northern California fires. *J. Geophys. Res,* **117**, D17301 (doi:10.1029/2012JD017627). Available on the Internet at http://www.agu.org/pubs/crossref/2012/2012JD017627.shtml.

Yao Y. (2012) Evaluation of the BlueSky Smoke Forecasting System and its utility for public health protection in B.C. The Canadian Smoke Newsletter, Spring/Summer Issue, pp. 17-19.