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An Automated System for Evaluating BlueSky Predictions of Smoke Impacts on Community Health and Ecosystems

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Please note: staffing for this project changed significantly mid-way through this project; the original contact PI was Susan O'Neill.

Brief summary of project background and objectives.

Predictions of smoke impacts on communities and ecosystems are currently being made by the BlueSky smoke forecast system; providing real-time predictions of surface smoke concentrations from prescribed fire, wildfire, and agricultural burn activities. Currently operational in the Pacific Northwest, BlueSky has already a demonstrated success regarding what inter-agency collaboration can accomplish. A critical component of BlueSky that needed to be addressed was the development of an automated verification system to evaluate predicted impacts from smoke on communities and ecosystems. A verification system is necessary because land managers need to evaluate their burn decisions against potential National Ambient Air Quality Standard (NAAQS) exceedences. To achieve this, the verification of predicted concentrations against observed must be provided in a timely (*i.e.* real-time) manner. Thus the original proposal included two major components: 1) improving existing monitoring systems to make the data available in real-time (*e.g.*, in a manner similar to the Washington State Department of Ecology, WSDOE); and 2) implementing a software system that compares these observational data with the smoke concentration fields predicted by BlueSky.

Directly and indirectly, BlueSky has sparked several inter-agency field projects. Projects include JFSP funded field projects of wildfires (predominately conducted on the West Coast and Northwest) and prescribed burns on the Atlantic Coast. In 2004, EPA Administrator Mike Leavitt tasked the EPA with implementing BlueSky RAINS for the 2005 fire season across all Western States for wildfires. The result was the multi-agency 2005 BlueSky RAINS West (BSRW) demonstration project. The project developed a new partnership among the USDA Forest Service Pacific Northwest, Rocky Mountain, Pacific Southwest, and Southern Research Stations; Forest Service National Forest Systems and State and Private Forestry, EPA; and the Department of the Interior. One of their recommendations:

> ***Recommendation:***
>
> - ***Develop an approach to continue testing, evaluating, and validating performance.***
>
> *We recommend initiating a combination of realtime validation from monitoring data, expansion of ambient monitoring capabilities for prescribed and wild fires, quantitative testing of model results against existing observational datasets, and specialized field experiments. This approach may be possible through the Joint Fire Sciences Program (JFSP). To be done correctly using all the methods above, this work would require several million dollars, and thus full funding would likely require leveraging competitive grant or special project funds with agency base funding.* [*BlueSky RAINS West Demonstration Project – Final Report*].

Summary of Findings

The primary objective of this study was to implement an automated system to compare predicted and observed $PM_{2.5}$ concentration. To that end, the project has been successful in spite of serious logistical and administrative obstacles (these are noted in the Final Comments section.) The following two pictures illustrate the results and deliverables for this project. Figure 1 is snapshot of the Air Quality sites in Washington state and its neighbors with a tabular listing of details at those sites. Figure 2 is a time series of observed PM2.5 versus that predicted by BlueSky (12km met data grid) at a location near Coeur d'Alene, ID for the period 1 Jan 2007 through 11 Sep 2007 (Note: the site was picked randomly from AirNow sites that are within the 12km Pacific Northwest BlueSky modeling domain). It is curious to note how little smoke BlueSky predicted in the earlier part of the year. The large disparity is likely due to smoke from fireplaces and wood burning stoves.

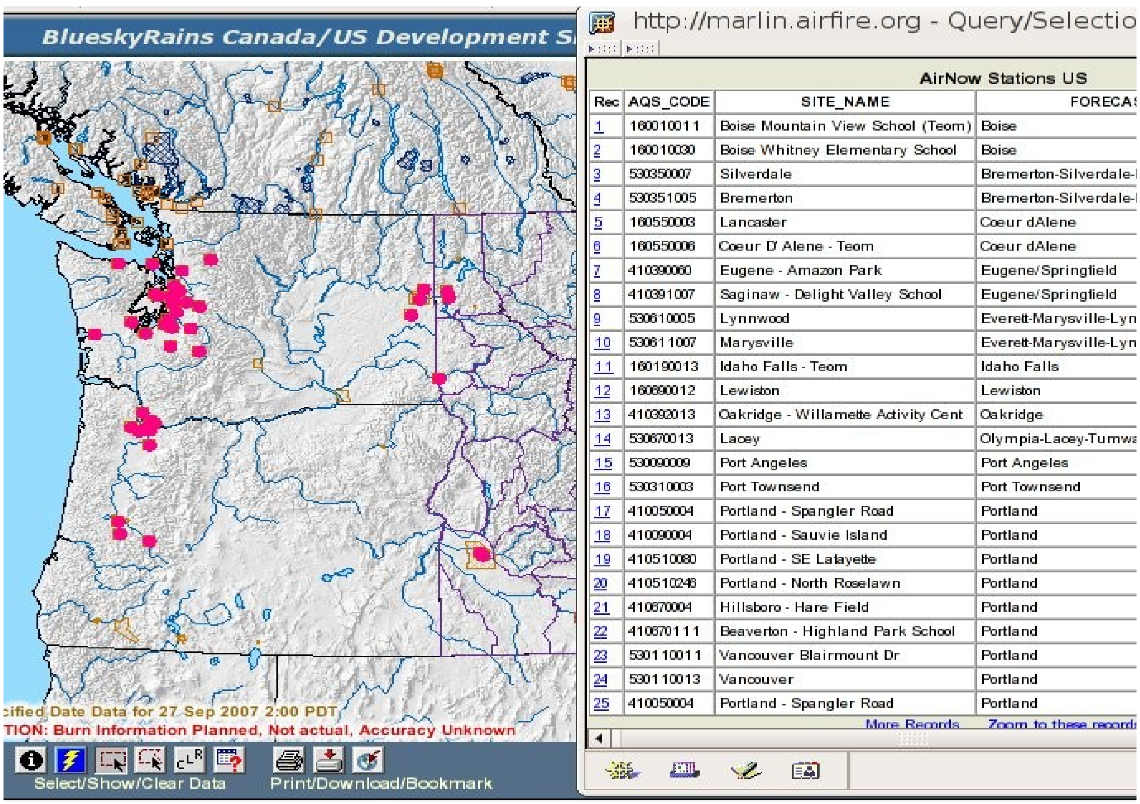

Figure 1: AirNow air quality measurements sites in the Northwest.

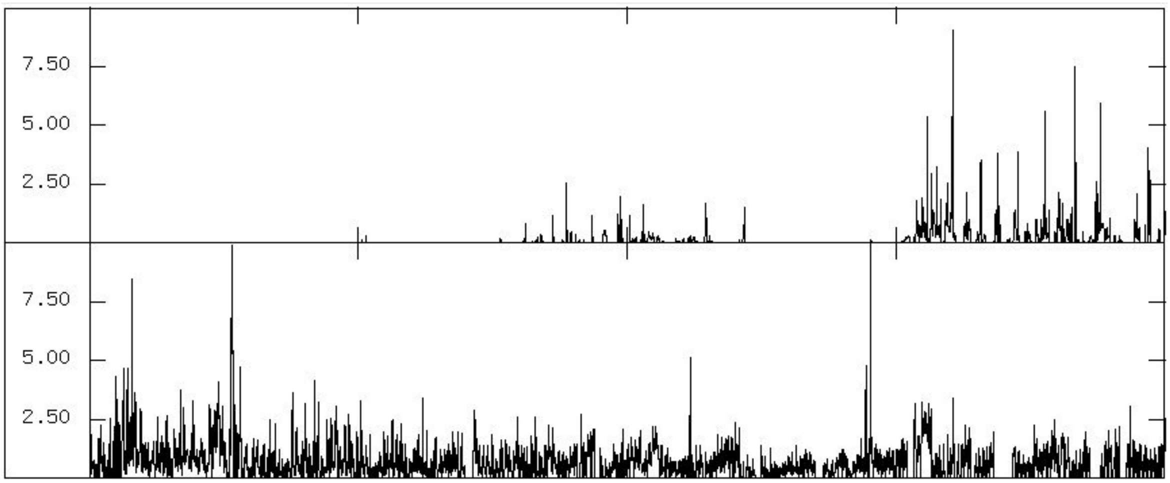

Figure 2. Top graph, predicted PM2.5 at an AirNow sensor location near Coeur d'Alene, ID. Lower graph AirNow observation. PM2.5 concentration (vertical axis, units of ug/m³) Time (horizontal axis) starts on 1 Jan 2007 (12Z)

The remaining portion of this section highlights some key details and influences on the results of this project.

- **What a sensor measures differs from what is predicted by BlueSky.**

  This is the classic "apples and oranges" problem. Both BlueSky and the automated network of sensors are methods used to find the $PM_{2.5}$ concentration. Neither method is direct. Instruments use everything from light or beta ray scattering to filter packs (although these are not available in a near real-time environment). BlueSky uses a set of numeric models to attempt to get to the same value as those observed.

  Aside from the differences in how each system arrives at its result, the sources of $PM_{2.5}$ differ between the two. The sensor networks measures particles from anything, *e.g.* wildfire, car emissions, road dust *etc*. BlueSky's framework only includes sources from known fires or potential smoke from prescribed fires.

  A large (if not majority) of the sensors used in the network are in or near urban environments (these are the areas where smoke may impact a large number of the populace) which are also the locations with large amounts of background $PM_{2.5}$ from automobiles and other anthropogenic sources which BlueSky does not include in its predictions.

  Initial use of some of the statistics and long term data obtained by the automated BlueSky verification system include methods to remove the "background" $PM_{2.5}$ from the observed values. The automated verification system also generates a separate set of statistics for low and high impact regimes at each sensor site (currently, "high" reflects an observed $PM_{2.5}$ concentration that is 50% of the NAQ exceedence value).

- **Field study will remain an import aspect in model validation.**

  The standard location of air quality monitoring equipment (especially equipment used for long periods of time such as most in the AirNow network) is often dictated by the need to be close to a power source, ability to maintain it cheaply and concerns about where impacts from smoke may affect a large number of people. Fires, on the other hand are quite often in completely contrary locations. Field projects will remain necessary in order to provide the near fire fuel consumption and emissions to validate the models used within the BlueSky framework that predict the same.

- **BlueSky tends to under-predicts near fire smoke concentrations and over predict far field concentrations.**

  This is seen as a general trend for BlueSky's forecasts. Based on this and field observations, several projects are actively looking into why this occurs and how to improve the models used in BlueSky that lead to this trend.

- **Each numerical model present in the BlueSky framework contributes to the overall error.**

  BlueSky's design allows for the use of different numerical models at each stage in calculations for smoke impact. Each of these will have some uncertainty associated their results. The automated system can tell us the 'end result' uncertainty but we must keep in mind that each calculation used adds its own contribution to the overall uncertainty. During this project, the following components are seen as contributing the most to predicted $PM_{2.5}$ uncertainty:

  - **Fire "cores"** -- how many plumes are responsible for lofting smoke into the atmosphere at a fire's burning front. The simplistic approach is to use a single fire core but recent experiments and comparisons with prescribed burns have indicated that this may be the largest single source of errors in the predicted smoke concentration fields.

  - **Fuels** (source of, consumption and emission) – Only rarely do we have enough information to fully characterize a fire. Among the values lacking are the sources of fuels. Various fuel loading maps and a variety of consumption and emissions models are used to ultimately find the amount of smoke released during a fire. Early experiments show the choice of which fuel loading map and models to use shows changes near an order of magnitude.

  - **Boundary layer meteorology** – Scientific understanding of the dynamics of the boundary layer is currently viewed as a weakness in atmospheric sciences. On top of this, the methods/calculations used for boundary layer meteorology are one of largest recognized problems within numerical weather models. There are huge implications for all air quality models where dispersion is an important consideration.

  - **Plume rise**:-- Where smoke from a fire is distributed in the vertical. This aspect of the smoke forecast has large implications on the smoke concentration and differences in it near a fire and large distances downwind. With the recent changes in NAQ exceedances, judging impacts near and far from a fire will become more important.

- **Fire growth –** BlueSky has a limited ability to predict fire growth. Existing models, tend to require a large amount of user-intensive "tuning" that is dependent on each fire event.

- **There are many potential sources of error in current fire reporting systems.**

  The BlueSky framework produces its $PM_{2.5}$ forecast with inputs of fire, and potential fire, from many sources. Wildfire information is gathered from the ICS-209 reports. The report is not in place for BlueSky's benefit and the automated systems within BlueSky cull what they can from a source designed for other reasons. Its "human interface" for data entry is also prone to a variety of errors.

  Other sources of smoke include prescribed burns. Theses reporting systems suffer from a variety of errors in achieving an accurate burn forecast. Land managers/burn bosses often submit many more fires than they can realistically accomplish on a given day or during the prescribed burn season. This may be to insure they can burn under unknown, future meteorology conditions to dealing with limited resources, etc. However, regardless of the reason, these potential fires can persist over very long periods with actually occurring and when they do burn, the acres actually burned will vary considerably from what the land managers would have liked to have burn. Not to mention, every state may potentially have different reporting requirements or none at all. For, randomly selected fires in the Northwest, once a burn was accomplished, the report of that burn getting reported back into the system varied from as little as less than 24 hours to two weeks and in a few extreme cases, months.

Proposed and Deliverable Products:

Table 1. Crosswalk between proposed and deliverable products

Proposed	Deliverable	Status
Real-time web-accessible monitoring network integrating data from the states of Washington, Oregon, Idaho, and Montana and from federal agencies.	An automated system to acquire air quality data for observations that fall within BlueSky's modeling domain. The existing system is also being used to acquire AQ data over the continental United States, Northern Mexico and Southern Canada via the collaboration with the EPA funded AirNow system. http://marlin.airfire.org/website/bluecvs/viewer.htm	The products produced by the automated system are currently on the BlueSky RAINS development site: http://marlin.airfire.org/website/bluecvs/viewer.htm. Once the system has been determined to be stable it will be moved be available via the main BlueSky RAINS portal: http://www.blueskyrains.org/. We anticipate this to occur before the end of 2007, to coincide with the upcoming prescribed burn season.

Develop a real-time software system that compares observational data with the smoke concentrations fields predicted by BlueSky.	A PERL and SQLite based system that can be extended easily automated to acquire AQ, extract BlueSky predictions and perform a range of statistical operations.	Completed
Correlate predicted $PM_{2.5}$ concentrations with nephelometer scattering data.	The AQ data sets directly convert to $PM_{2.5}$	Raw scattering data is not available. The observational AQ data is converted to a $PM_{2.5}$ concentration before we obtain it.
Apply a suite of traditional statistical measures to compare predicted smoke concentrations with the observed smoke concentrations.	Automated system calculates a relative degree of $PM_{2.5}$ impact, Index of Agreement, Error, Bias, Normalized Error and Normalized Bias.	Completed
Investigate trends and relationships between the observations and the predictions	Web Accessible data set beginning mid-2005 through present	Completed
Display the statistics including their spatial variability and observed and predicted concentration time series on the web	Display of BlueSky predictions, AQ observations and limited statistical quantities via the BlueSky-RAINS web site	The complete suite of statistics is much too large to be made directly available. The most relevant subset will be available online (see first deliverable Status). Contact Dr Robert Solomon, robert@airfire.org, to obtain the database(s) containing the full suite of observations and statistics or to suggest others to place on-line that may be of interest.
Analyze 2002-2005 burn seasons in relation to meteorological and other parameters	Mid 2005 through the present has been and continues to be examined	The mid 2005 to present burn seasons have been completed in lieu of the 2002-2005 as it also intersects with numerous field projects involving BlueSky's forecasting ability.
Publications/Conferences	Northwest Regional Modeling Consortium Meeting, Seattle. An Automated System for Evaluating BlueSky Performance, 2007, 2nd Fire Behavior and Fuels Conference, San Destin, FL. BlueSky Annual Meeting, May 2007, Sun Mountain/Winthrope, WA.	An additional publication is planned to include observations taken during one or more of the recent field projects.

Software package	http://www.airfire.org/jfsp/bsverify/docs/bsverify.tgz	Completed. This is a direct link to an archived version of the code base. For inquiries about implementing or how to extend the capability of the model, contact Dr. Robert Solomon.

Additional deliverables (not in the proposal but in the 'spirit-of' those proposed):

- In addition to providing the proposed functionality using observed/predicted $PM_{2.5}$, the system developed can also be used to provide the same suites of analysis for both O_3 and PM_{10}. The BlueSky framework does not currently forecast PM_{10} concentrations and, in its current state, is unable to calculate O_3 impacts; however, both PM_{10} and ozone are being processed concurrently with $PM_{2.5}$ and archived in such a manner that if a prediction source (BlueSky or not) of either is provided, the statistical measures can be quickly and easily obtained.

- Statistical quantities, model performance, etc are also performed over diurnal, seasonal and annual cycles for hourly, daily peak hourly and average 24 hour $PM_{2.5}$ concentrations.

Final Comments:

Originally the project was to be fronted by PI's: Dr. Susan M. O'Neill (USDA Forest Service), Dr. David Levinson (US Dept of Interior BLM, MT/ID Airshed Group), Dr. Brian K. Lamb (Washington State University), Clint Bowman (Washington State Department of Ecology) and Dr. Sue Ferguson (USDA Forest Service). Illness in early 2005 forced Dr. Ferguson to reduce her involvement, and she passed away in December 2005. Dr O'Neill resigned from the Forest Service in October 2005, six months before the original project end-date. With a six month extension from Joint Fire Science, Dr. Robert Solomon took leadership for wrapping up the work, a nontrivial matter given that he had not been involved prior to this time.

BlueSky has been undergoing a large number of changes recently. In fact a complete rewrite of the code used in the framework was completed mid-2007 and will be distributed to the FCAMMS later this year. The code used to develop the automated system for BlueSky evaluation will be compatible with output from the old or new version of BlueSky. In fact, the system can use any source with a minimal amount of work since the tools used rely on freely available, open-source code and packages. However, it is currently limited to operating in a Unix/Linux environment but is not inherently limited to that platform and could possibly be ported to others.

The BlueSky audience has also grown and changed with time and is driving changes in the design and tools used for displaying information. We hope to continue to include the products generated via the automated system of verification with all these methods and will support its inclusion in future BlueSky development.