Final Report

Expansion of the ClearSky Smoke Forecast System For Management of Agricultural Biomass Burning In Eastern Washington

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Executive Summary

To improve the capability of the Washington Department of Ecology to make burn/no-burn decisions related to agricultural field burning, the Laboratory for Atmospheric Research (LAR) at Washington State University has expanded the ClearSky smoke forecast system to include eastern Washington. The ClearSky system was developed in 2002 with support from the Idaho Division of Environmental Quality and applied for the Fall 2002 burn season to aid smoke management for grass field burning in northern Idaho. The Washington Ecology implementation of ClearSky for eastern Washington became operational beginning in July 2003 and provides automated, daily simulations of smoke plumes from agricultural burning. With the 2003 addition of eastern Washington and the Clearwater Valley of Idaho, the area treated by ClearSky has expanded to encompass the landscape within the red rectangle in Figure 1. An authorized smoke manager interacts with the ClearSky system to define field-burning scenarios using an interactive (password gated) web-application, as shown and described in Figure 2. Smoke forecast results are generated by an overnight CALPUFF model run. An animation of the scenario hourly smoke concentrations as predicted by CALPUFF is viewable on the ClearSky web site early the next day, as shown in Figure 3. The remainder of this report discusses in greater detail the ClearSky system, its functionality, design, implementation, data products and potential for future work and enhancements.

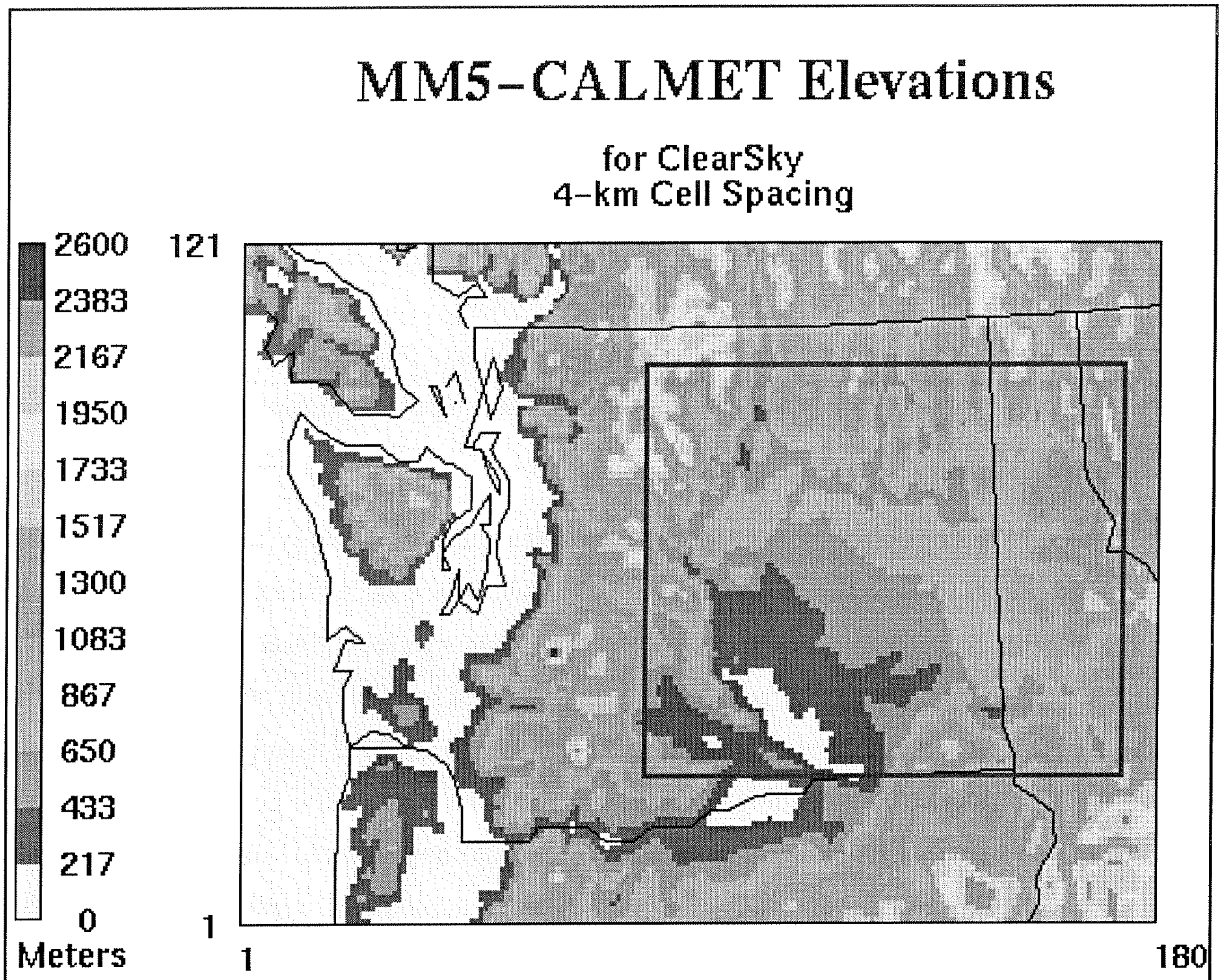

Figure 1. Summer-Fall 2003 ClearSky Domain; background is 4-km terrain from MM5. Red box includes regions in Idaho and Washington for which ClearSky applications have been developed.

9/35 ☑ Cnt: 4 Acr: 83 Start: 10 End : 16 Burn: 83	9/36 ☑ Cnt: 40 Acr: 2263 Start: 10 End : 16 Burn: 2263	9/37 ☐ Cnt: 53 Acr: 2274 Start: 10 End : 16 Burn:	9/38 ☑ Cnt: 80 Acr: 3509 Start: 10 End : 16 Burn: 2000	9/39 ☐ Cnt: 42 Acr: 1699 Start: 10 End : 16 Burn:	9/40 ☐ Cnt: 4 Acr: 471 Start: 10 End : 16 Burn:	9/41 Cnt: 0 Acr: 0
8/35 ☐ Cnt: 9 Acr: 457 Start: 10 End : 16 Burn:	8/36 ☐ Cnt: 9 Acr: 583 Start: 10 End : 16 Burn:	8/37 ☑ Cnt: 28 Acr: 1197 Start: 12 End : 16 Burn: 1197	8/38 ☐ Cnt: 12 Acr: 465 Start: 10 End : 16 Burn:	8/39 ☐ Cnt: 3 Acr: 160 Start: 10 End : 16 Burn:	8/40 Cnt: 0 Acr: 0	8/41 Cnt: 0 Acr: 0
7/35 ☐ Cnt: 6 Acr: 467 Start: 10 End : 16 Burn:	7/36 ☐ Cnt: 2 Acr: 26 Start: 10 End : 16 Burn:	7/37 ☐ Cnt: 2 Acr: 86 Start: 10 End : 16 Burn:	7/38 Cnt: 0 Acr: 0	7/39 Cnt: 0 Acr: 0	7/40 Cnt: 0 Acr: 0	7/41 Cnt: 0 Acr: 0
6/35 Cnt: 0 Acr: 0	6/36 Cnt: 0 Acr: 0	6/37 Cnt: 0 Acr: 0	6/38 Cnt: 0 Acr: 0	6/39 Cnt: 0 Acr: 0	6/40 Cnt: 0 Acr: 0	6/41 Cnt: 0 Acr: 0

Figure 2. Screen shot showing an example of the ClearSky web-site application for constructing a field burn scenario. Each of the cells in this image has a township and range (TR) address in the upper left corner. For example, the top left cell shown represents Township 9, Range 35, and the lower right cell represents TR 6/41. For the block at TR 9/35, the box was checked to include all the available acreage (four fields ready to burn for a total of 83 acres) in that block in the burn scenario. TR 9/36 was also checked for inclusion of all acreage; however TR 9/38 was checked also, but the acreage was modified to 2000 acres, less that the acreage available. TR 8/37 was checked, and also modified for the start time of burning. When the user submits a scenario such as this one, the scenario is given a name such as W010b02840ac1, meaning Washington State, 10 TR-blocks including 2840 acres to be burned.

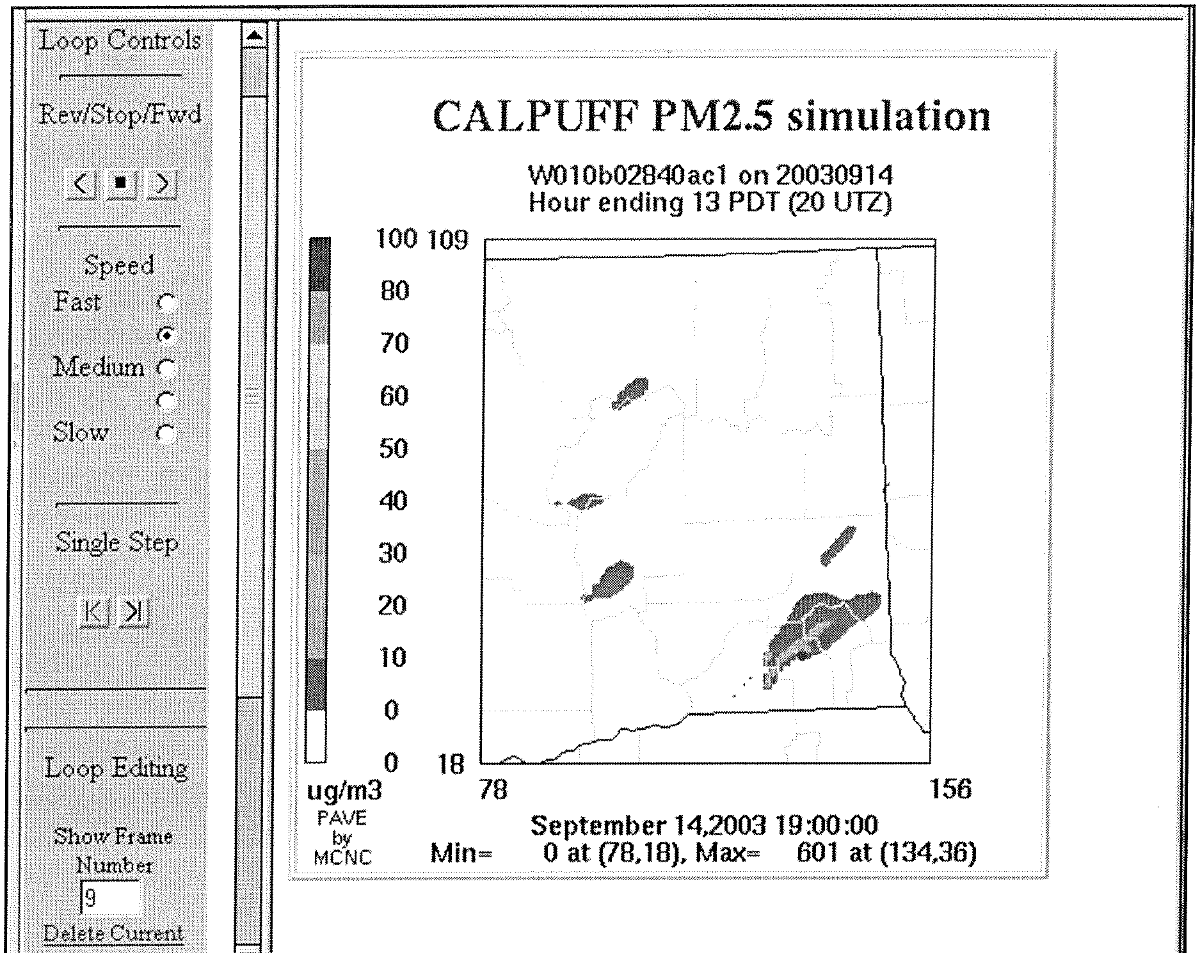

Figure 3. Example of a single frame from ClearSky 24-frame animation for eastern Washington for September 14. Frame shows predicted mass concentrations for PM2.5. Left side shows available animation controls.

ClearSky Functionality for the Agency User

ClearSky was conceived as a tool to enable smoke managers to envision the likely effects of alternative choices in the permitting of agricultural burning. The user, one or more members of Ecology's smoke management team, create field burning scenarios via a password protected web-application at the ClearSky web-site (www.ClearSky.wsu.edu) by selecting acreage to be burned during the following day. The user's selection of acres to burn is constrained by the acres known to be available to burn from the Ecology database that results from processing field-burning permit application forms. ClearSky runs overnight. Then the next morning the user can access the ClearSky website and review the predicted results, shown as animations of PM2.5 concentrations, over the region of interest for the (now current) day. Also, a default scenario is run automatically, without user activity being required, each night. The default scenario provides the users with a consistently defined scenario running every day, permitting the user to develop a sense of the day-to-day variation in the predictions. Both the generation of scenarios and the viewing of scenario prediction animations are password protected.

System Design Overview

The ClearSky system employs daily MM5 weather forecasts with 4-km horizontal grid spacing to drive the CALMET/CALPUFF modeling codes to simulate the dispersion of smoke from virtual (hypothetical) agricultural burns. The modeling domain for ClearSky is based upon a relatively large, gridded domain of 4-km cells, shown as a terrain elevation map in Figure 1; however the CALPUFF dispersion results for eastern Washington are displayed in a smaller, locally focused window (Figure 3). The University of Washington (UW) operates the Mesoscale Meteorological Model version 5 (MM5) twice daily for a series of nested domains to make weather forecasts for the Pacific Northwest. In ClearSky a 4-km MM5 forecast, covering PDT hours 5 AM to 5 AM the following day, is used to provide meteorological forecast data as input to CALMET, a diagnostic wind field model. MM5 results are also used to drive the MCIP Models-3 meteorological processor. The results from both CALMET and MCIP are used to generate input meteorological data required for the CALPUFF plume dispersion model. Smoke emissions are modeled as PM2.5 using CALPUFF. Emissions are based on a scenario defined by user interaction with the ClearSky web-application, and with reference to Ecology's agricultural burning permit database. The web-application for scenario generation is shown in

Figure 2, as mentioned above, and is further described in a subsequent section. Once meteorology and emissions are both prepared, CALPUFF is run for the 24-hour forecast period beginning at 5 PDT. Upon completion, the PM2.5 concentration predictions are visualized using the PAVE graphics tool, and exported as GIF files. These images are then available to users for viewing as animations via the ClearSky web site. Figure 3 shows a screen shot from one of these animations.

Analysis of Ecology Field Registration Data

Ecology makes a text file listing the fields registered and eligible for field burning available for ClearSky use. The Ecology data is organized in terms of burn-identifiers that each represent a potential burn of one to several locations within an area and under common management and ownership. Acreages are provided by burn-identifier, but not by locations within burn identifier, thus the data is analyzed to attribute acreages to specific locations using rules provided by Ecology (discussions with S. Nolph and J. Jones). TRS locations are converted to latitude-longitude locations and then to Lambert Conic Conformal (LCC) coordinates (using a LCC projection with a center at 49°N, 121°W). The analysis process results in data describing for each TR-block the number of fields and the total acreage. A TR-block is defined as the aggregate of the sections within a given Township and Range intersection; thus each block includes as many as 36 sections (each of one square mile), but fewer when the block is truncated by a state boundary. The analysis process also results in a listing of fields that are available to burn, with their attributed acreage and location, both in the TRS and LCC systems, in addition to other information such as crop type and residue loading. The data that results from this analysis of Ecology database contents are used to 1) inform the scenario definition web-application and 2) construct the emissions for CALPUFF for the scenarios generated through the users' interaction with that web-application.

Web-application for Scenario Generation

Using the TR-block denominated data from the analysis step described above, the ClearSky web-application for scenario generation offers the user the opportunity to define a burn scenario by specifying acreage to burn and (optionally) begin and end burn times at the TR-block level of detail. Figure 2 shows a portion of the eastern Washington scenario generator from a September day, and illustrates the user's actions as explained in the caption. Some blocks are seen to have no eligible fields; blocks with zero acreage available are shaded gray. When the user has selected acreages to burn on various blocks as desired, and perhaps modified the burn times, the user submits the scenario and ClearSky returns a scenario identifier defined as:

W	for eastern Washington,
nnn	the number of blocks activated for burning, total for this scenario,
b	character ''b' as delimiter for block count,
nnnnn	the number of acres requested for burning, total for this scenario,
ac	characters 'ac' as delimiter for acre total,
n	integer, typically 1, to provide for uniqueness of scenario names.

Thus, the default scenario for eastern Washington is named W010b02840ac1, for a burn requesting 2840 acres over 10 blocks.

Interpretation of the Emissions Scenario to the Field-Level of Detail

The scenarios defined by the users are processed with reference to the detailed data about the field data that results from the analysis stage. For each block for which burning is requested, the field data file is searched for fields within that block. If fields are found in excess of the acreage requested, then an iterative procedure to select a good set of fields is executed. This involves multiple random selections of the fields within a block, subject to the acreage requirement, and an area-weighted distance calculation designed to represent the spatial distribution of a set of fields. In this way an assortment of specific fields with determined locations and specific acreages resulting in a comparatively large spatial dispersion are identified for use for a specific TR-block. All blocks in the scenario are treated in this way, arriving at a complete list of fields to be burned. This step has the overall effect of converting a scenario described by TR-blocks and acreages into a specific list of fields.

The burn times (begin and end) for specific fields are determined with respect to 1) the burn times received from the scenario generation application described above for the encompassing TR-block, and 2) the field acreage and rate of burn applicable for the field locality. To this end, rates of burning associated with different areas (defined by county location of fields) are applied to determine how long a field requires to burn, thereby fixing the rate of field burning in terms of area per hour, for each field being burned in the scenario. Following this determination, fields that can be burned in less than the time span available (from the web-application, either as stipulated by the user or the default) have their ignition times staggered through the overall burn window for the TR-block in which they are found. To summarize this step of the emissions process, the TR-block requests for acreage to be burned are converted into specific fields at specific locations with a controlled distribution of burn times and a high degree of spatial dispersion.

Field-Level Detail Emissions Scenario Conversion to CALPUFF Emissions

For CALPUFF, each field that burns is represented as two types of source, a buoyant area source and a buoyant line source. The bulk PM2.5 emissions from a field are therefore split into area and line source emissions, using a ratio of 80/20 for smoldering emissions to flaming emissions, assuming that the flaming emissions are associated with an advancing line of flame. It is assumed that 0.3% of fuel loading (crop residue) is converted to PM2.5. For both source types, a variety of parameters that determine plume-rise behavior for the emissions in CALPUFF are set and are written to the relevant output emissions files. Two files result from this step, the LNEMARB.DAT file of arbitrarily varying buoyant line source emissions and the BAEMARB.DAT file of arbitrarily varying buoyant area source emissions.

Smoke Dispersion Forecasting Using CALPUFF

Once the foregoing steps are completed CALPUFF, a plume dispersion model that treats plumes as a series of puffs, runs and generates a file containing the gridded hour-average cell-center surface level PM2.5 concentrations for the entire domain shown in Figure 1. Post-processing of the concentration file results in hourly images of the predicted PM2.5 concentrations. These images (GIF files) are then made available via the website for review by the smoke managers by the early morning of the day being forecast.

Possible Future Work

It is desirable to pursue further enhancements to the ClearSky system for eastern Washington:

- Automated near real-time capture and display of Washington PM monitoring data.
- Display of PM monitoring data within animations of predictions.
- Post-hoc scenario definition and run, to support study of system capability.
- Rapid turn-around scenario generation, modeling and animation.

- Export of ClearSky predictions to the BlueSkyRAINS system.
- Comprehensive evaluation of ClearSky PM2.5 simulations

Conclusion

ClearSky is a state-of-the-art application of widely recognized modeling elements, developed at the Laboratory for Atmospheric Research at WSU, developed to address pressing responsibilities of state and tribal managers with respect to smoke from agricultural burning. With support from Idaho and Washington environmental agencies, ClearSky is providing technical leadership in this nascent field, and is collaborating with the BlueSkyRAINS project of the US Forest Service to contribute to the larger smoke management issue. Also, ClearSky and BlueSkyRAINS have the potential to assist in the exploration and management of cross boundary smoke transport, both across state and tribal borders, but also across the US-Canadian border.