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Research article

Modeling Volcanic Ash Resuspension with Dustran

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Abstract

Resuspension of volcanic ash can be problematic for a number of reasons. Ash resuspension can reduce visibility, increase concentrations of atmospheric particulate matter (respiratory irritant), damage machinery and clog air intake systems. While these issues are the same problems created by ash emitted during the initial eruption, resuspension can persist for months, resulting in prolonged problems. For example, this study was initiated due to concerns over a future eruption and subsequent ash resuspension impacting operability of facilities in the Columbia Basin (in and around Richland, Washington). This paper addresses the applicability of the DUSTRAN model to predict the resuspension of volcanic ash. Specifically, an ash resuspension event following the 1980 Mount St. Helens eruption was modeled, and compared to historic measurements. Additionally, generic ash resuspension events were modeled and compared with published results made under similar meteorological conditions. DUSTRAN was able to predict the Mount St. Helens ash fall resuspension within expected uncertainties. Further, the estimates of airborne particulate matter concentrations made with DUSTRAN under several wind speed conditions were consistent with more recent measurements of ash resuspension.

Keywords: Ash; Resuspension; Modeling; Transport

Intoduction

The Columbia Basin's exposure to volcanic hazards results from regional proximity to the Cascade Range (which includes several prominent volcanoes). A general assessment of volcanic hazards and eruptive history for Cascade volcanoes was compiled by the U. S. Geological Survey (USGS) in Open-File Report 87-297, *Volcanic Hazards with Regard to Siting Nuclear-Power Plants in the Pacific Northwest*. The USGS has refined and updated its volcanic hazard assessments, mostly by individual volcanoes (e.g., Open-File Report 95-497, *Volcanic-Hazard Zonation for Mount St. Helens, Washington, 1995)*, and currently maintains an Internet site of volcanic hazard references at http://vulcan.wr.usgs.gov/Hazards/.

These assessments indicate that the Columbia Basin is sufficiently distant from Cascade Range volcanoes that hazards from lava flows, pyroclastic flows and surges, landslides, lahars, and ballistic projectiles are below a probability of concern. By far the most probable volcanic hazard in the Columbia Basin is tephra (ash) fallout from dispersal of an eruptive plume. Small fragments of lava or rock blasted into the atmosphere may be carried great distances before falling back to the earth to form a volcanic ash deposit. Tephra deposits may vary widely in thickness and in particle size, depending on distance from the source and the magnitude and character of the eruption. Besides the hazard of added structural load from a large tephra deposit, even small tephra clouds bring abrasive airborne particles that can clog filters and interfere with ventilation and combustion processes, impair visibility, and greatly increase wear in exposed machinery. Fresh ash with moisture may be corrosive and sufficiently conductive to cause shorting in exposed electrical equipment. Additionally, severe ash fall could overburden intake filters with particulates and reduce the amount of air available for operation of safety equipment. Resuspension of ash can also impact agriculture, including farming and livestock operations [1]. While the initial ash plume increases particulate matter concentrations for a few days, resuspension of deposited ash by wind could periodically elevate particulate matter concentrations for months. For example, in the Columbia Basin, the daily average wind speed exceeds 5 m/s approximately 10% of the time (Figure 1). Evaluation of existing ash resuspension data [2-4] indicates that elevated daily average particulate matter concentrations (>100 μg/m^3) within the ash fall footprint can be expected when wind speeds exceed 5 m/s.

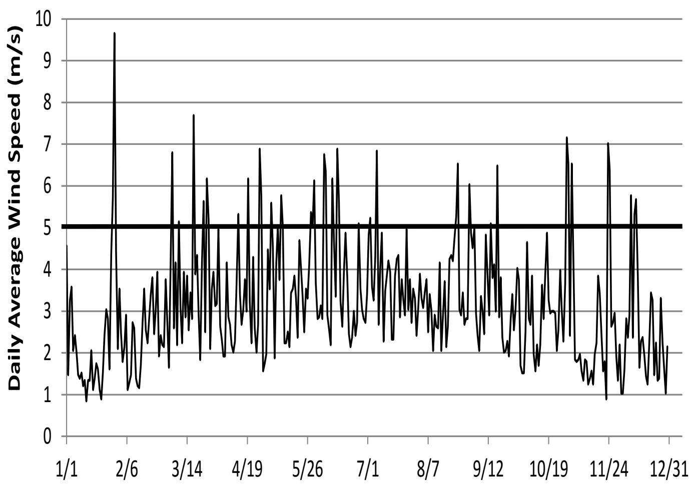

Figure 1. Daily average wind speed (2004) measured within the Columbia Basin [5]

One way to evaluate the impact that resuspension of volcanic ash could have is to model the airborne concentrations of particulate matter that are generated during elevated wind events. Pacific Northwest National Laboratory (PNNL) previously developed an atmospheric modeling system DUSTRAN [6] capable of modeling the resuspension and transport of dust from soil [7]. More recently, USGS has developed Ash3D [8], a three-dimensional Eulerian atmospheric model for tephra transport, dispersal, and deposition created to study and forecast hazards of volcanic ash clouds and tephra fall. While Ash3D can be used to predict ash fall, DUSTRAN can be used to predict resuspension of ash following a volcanic event. Here we provide a proof-of-concept model evaluation of the ability of DUSTRAN to model resuspension of volcanic ash.

Model Description

The DUSTRAN model is actually a suite of models, integrated within a geographic information system (GIS) framework, which is capable of modeling the emission and transport of gases and particulate matter. It has previously been used to model point sources, line sources, and area sources. The modeling suite includes a meteorological model (CALMET), a gridded Eulerian transport/dispersion model (CALGRID), and a windblown dust emission model (AREADUST). Once the meteorological model (CALMET) is supplied with some initial terrain, land cover, and meteorological information (either real or synthetic data), it calculates a gridded wind field that is used as input to the CALGRID model. In addition to the wind field, other similarity theory meteorological parameters are calculated by CALMET (e.g., friction velocity). AREADUST then uses the gridded friction velocity field to estimate the resuspension of particulate matter from the soil surface [6,7]. Finally, CALGRID is used to model the transport of particulate matter and calculate the concentrations across the entire modeling domain. In this manner, DUSTRAN can calculate the concentrations of particulate matter in air that result from resuspension over wide areas (hundreds of square kilometers) and durations (days).

This scheme is very similar to the approach that other ash resuspension/transport models use. For example, FALL3D can implement different resuspension algorithms, all of which rely on the friction velocity as the primary input [4, 9, 10]. FALL3D can also use multiple meteorological input models (including CALMET). A gridded Eulerian model is then used to simulate the dispersion of ash across the modeling domain. Another ash resuspension model applied to ash transport is NAME (Numerical Atmospheric-dispersion Modeling Environment) model, a Lagrangian particle tracking model where the ash resuspension is a function of the friction velocity [11].

The meteorology and transport models embedded in DUSTRAN (CALMET and CALGRID) were developed for regulatory application, and have been evaluated under a variety of conditions [5, 12-15]. However, these models do not predict the generation of airborne particulate matter from the soil surface. The PNNL-developed model AREADUST is used to calculate vertical dust flux as an input to CALGRID [7]. AREADUST follows the form recommended by [16], where the vertical dust flux is proportional to the friction velocity, but only when the friction velocity is greater than a threshold friction velocity. AREADUST currently uses a threshold friction velocity of 20 cm/s, which is a widely cited value for soil [17]. Note however that for modeling Icelandic ash resuspension events, [3] chose a threshold friction velocity of 40 cm/s. In addition to the general dust flux formulation recommended by [16], AREADUST incorporates parameterization schemes to scale the vertical dust flux as a function of soil moisture, vegetation cover, and particle size. These parameterization schemes all derive from previously published literature [18]. In addition to emission, AREADUST also calculates the deposition of particulate matter across the modeling domain, including scavenging by vegetation. A published evaluation of windblown dust using DUSTRAN [7] demonstrated that DUSTRAN provides a good estimate of windblown dust concentrations (Figure 2), which provides further confidence in the AREADUST algorithm.

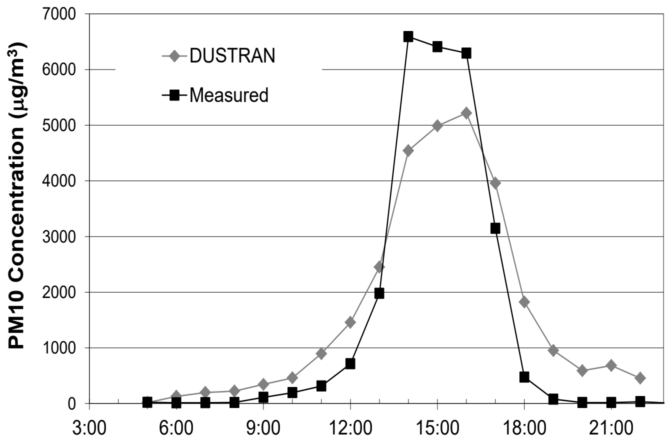

Figure 2. Comparison of modeled (DUSTRAN) and measured PM10 concentrations during a dust storm [7].

While the proven track record of the underlying models used by DUSTRAN, and the associated modeling study, provide confidence that the application of DUSTRAN is likely appropriate for this study, some modifications of DUSTRAN were necessary in order to address ash resuspension. These modifications included integrating soil characteristics typical of soil covered in ash, adjusting for ash particle size distribution, threshold friction velocity, and turning off the vegetation mask.

Modeling Scenarios

This evaluation used three simplified scenarios using the same modeling domain as previous work [7]. While real terrain data was used, simplified meteorological, vegetation coverage, and particle size distribution inputs were used. The wind velocities chosen were 2.5, 5, and 10 m/s at 250 degrees (wind out of the west-southwest). The attenuation of ash resuspension by vegetation was turned off (vegetation mask set to 1); this was based on the assumption that deposited ash would mimic bare ground. Initially after deposition, the vegetation would be covered in ash. After some time, the ash would fall from vegetation onto the surface. This surface ash would not be impeded from resuspension the way soil in a vegetated area is; the vegetation root structure and soil cryptogrammic crust would not be present in the surface ash. The vegetation height would reduce surface wind speeds, but this is accounted for in the model by the calculation of the surface roughness length. The vegetation mask is used by the model to account for mechanisms that prevent resuspension regardless of wind speed (e.g. roots). Therefore, turning off the vegetation mask was deemed appropriate for modeling re-suspension of volcanic ash. The particle size distribution was set following the general distribution observed in ash that was deposited in eastern Washington following the Mount St. Helens eruption in May 1980 (Table 1; Durant et al. 2009). This work used laser diffraction particle size analysis to provide a semi-continuous size spectra. The relative abundance in each DUSTRAN size class was calculated from the published results [19].

DUSTRAN Size class	1	2	3	4
Size range (µm)	1-2	2-20	20-50	50-100
Relative abundance	3%	45%	34%	18%

Table 1. Particle size distribution of ash used for DUSTRAN input [19].

The meteorological inputs were chosen to correlate with the conditions present following the Mount St. Helens eruption and more recent ash resuspension events in Argentina and Iceland. For example, a 2.5 m/s wind speed case is consistent with wind speeds measured on the Hanford Site from November 1 1980 through November 7 1980, and the 5 m/s scenario represents conditions from July 28 1980 to August 5 1980 [2]. Particulate monitoring conducted at two locations on the Hanford Site in 1980 provide data that can be used to compare against the modeled results [2]. Similarly, although complete model reconstructions of the Iceland [3] and Argentinian [4] events were not practical, the 5 and 10 m/s scenario was consistent with conditions at Heimaland (Iceland) and Argentina. For all cases, the area of interest was within the ash accumulation area, and the DUSTRAN concentration range was the range of concentrations predicted in the area between the 1980 monitoring sites [2]. One shortcoming of the approach is that time-varying meteorological inputs were not used, only daily average conditions. Also, the measurements include particulate matter from resuspension as well as normal background levels of particulate matter, whereas the model only predicts the resuspended ash concentrations. DUSTRAN was only run for particles in the 2 - 20 µm size class since this was the size class with the highest abundance and greatest likelihood of longer range transport. Additionally, available measurements were for PM_{10}, and the 2 -20 µm size class most closely matches a PM_{10} measurement. Since the model inputs were not optimized and the size class did not exactly match measurements, the level of agreement between DUSTRAN and historical measurements can only be considered on an order-of-magnitude scale here. However, to help make a more direct comparison between the modeled and measured concentrations, a background particulate concentration of 15 µg/m^3 was added to all DUSTRAN results. This concentration is typical of background PM_{10} concentrations across the Columbia Basin [20].

Results and Discussion

For the 5 m/s wind speed scenario, DUSTRAN estimated particulate matter concentrations (2-20 µm size fraction) to vary between 45 and 165 µg/m^3. Between July 28 and August 5 (1980), when wind speeds averaged 5 m/s, measurements of airborne particulate matter concentrations ranged between 100 and 150 µg/m^3 at the two monitoring locations [2]. A second, lower wind speed case was also simulated. This case represented the first week in November 1980, when wind speeds were about half of the initial test scenario. During this period, the particulate matter concentrations measured on the Hanford Site ranged between 15 and 25 μg/m^3 [2]. Similarly, DUSTRAN estimated concentrations between the monitoring locations to vary between 16 and 35 μg/m^3 (Figure 2).

An additional comparison between DUSTRAN and field measurements can be done using data collected in Iceland following a 2010 volcanic eruption and data collected in Argentina after a 2011 volcanic eruption. From the Icelandic dataset [3], daily average PM_{10} concentrations between 50 and 150 μg/m^3 were measured when wind speeds were approximately 5 m/s. The concentrations of resuspended ash measured were of a similar magnitude as the 5m/s DUSTRAN model scenario presented above. For the Argentinian and Icelandic events, with wind speeds of 10 m/s, PM_{10} concentration measurements varied between 1200 and 4000 μg/m^3 (Figure 3). Similarly, DUSTRAN model simulations resulted in estimates of particulate matter concentrations ranging from 600 to 4000 μg/m^3 (Figure 3).

For an additional comparison, DUSTRAN model results were compared to measurements of resuspended ash at various wind speed conditions. The best fit trend line agrees well with the model estimates at all three wind speed cases (Figure 3). This provides further evidence that the emission algorithm within DUSTRAN is correctly modeling the resuspension phenomena.

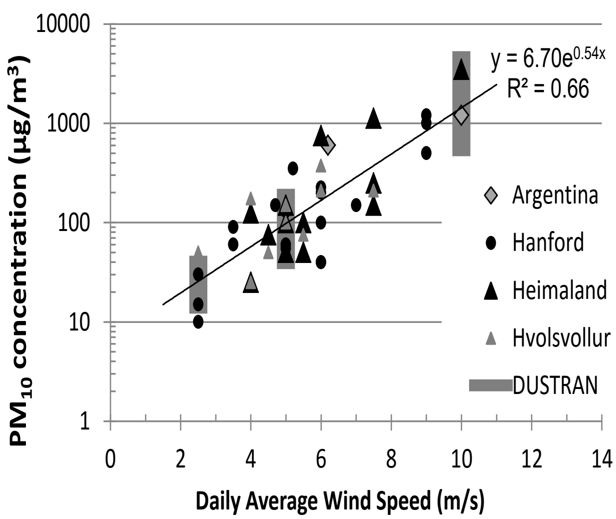

Figure 3. Selected daily average particulate concentrations measured within ash fall footprints following three volcanic eruptions. Data estimated from published graphics [2-4].

Conclusion

It was anticipated that the DUSTRAN model would be capable of modeling the resuspension and transport of ash by winds. This expectation was initially based on published studies where the CALMET and CALGRID models were shown to correctly predict meteorological conditions and transport phenomena. Additionally, a study of windblown dust on the Hanford Site provided confidence that the AREADUST model, which is used to predict vertical dust flux, was sufficiently robust. While this previous work promoted confidence in the model, a proof-of-concept model evaluation was also conducted. Although limitations in previous data made direct comparison impractical, a general comparison to measured particulate concentrations following resuspension of volcanic ash was undertaken. This comparison demonstrated that the DUSTRAN model was predicting ash resuspension within the range of expected uncertainty.

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