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Simulation of windblown dust transport from a mine tailings impoundment using a computational fluid dynamics model

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ABSTRACT

Mining operations are potential sources of airborne particulate metal and metalloid contaminants through both direct smelter emissions and wind erosion of mine tailings. The warmer, drier conditions predicted for the Southwestern US by climate models may make contaminated atmospheric dust and aerosols increasingly important, due to potential deleterious effects on human health and ecology. Dust emissions and dispersion of dust and aerosol from the Iron King Mine tailings in Dewey-Humboldt, Arizona, a Superfund site, are currently being investigated through in situ field measurements and computational fluid dynamics modeling. These tailings are heavily contaminated with lead and arsenic. Using a computational fluid dynamics model, we model dust transport from the mine tailings to the surrounding region. The model includes gaseous plume dispersion to simulate the transport of the fine aerosols, while individual particle transport is used to track the trajectories of larger particles and to monitor their deposition locations. In order to improve the accuracy of the dust transport simulations, both regional topographical features and local weather patterns have been incorporated into the model simulations. Results show that local topography and wind velocity profiles are the major factors that control deposition.

1. Introduction

The Iron King mine tailings site located in Dewey-Humboldt Arizona is a potentially hazardous source of contaminated aerosols. The Iron King Mine tailings and nearby inactive smelter site were officially added to the Environmental Protection Agency (EPA) national priorities list in 2008. The smelter was operational from 1904 till 1969. It was used to extract lead, gold, silver, zinc and copper at different times. The 220,000 m^2 tailings were impounded on property (EPA, 2010). Sediment from these mine tailings has significantly elevated concentrations of both lead (up to 0.20 wt%), and arsenic (up to 0.24 wt%), amongst other toxic species. Additional tests of top soil from nearby sampling sites have shown elevated contaminant concentrations outside the boundaries of the Iron King Mine property. The spread of the contaminants is in part caused by aeolian dust transport from the mine tailings.

Aerosol and dust transport is a potentially dangerous mechanism for spreading contamination because of the high mobility of the smaller suspended particulate, especially for accumulation mode aerosols (<1 μm diameter). This particle size range is potentially hazardous to human health since they have the potential to deeply penetrate in the respiratory system. The relatively large diffusivity of these aerosols causes them to have an increased likelihood to deposit in the smaller airways such as the alveolar regions of the lungs (Hinds, 1999). Long-term exposure to these aerosol and dust particles may cause adverse health effects. Lifetime excess cancer risks for a similar arsenic contaminated copper mine located in Hayden, Arizona, was estimated to be 1 in 5000 by the Arizona Department of Health Services (Public Health Assessment, 2002), and up to 1 in 100, as estimated by EPA (Earth Justice, 2003).

In this work, we apply a Computational Fluids Dynamics (CFD) software tool, ANSYS FLUENT, to investigate aeolian transport and deposition rates of aerosols emitted from the Iron King Mine tailings to the surrounding region. The CFD is based on the turbulent Reynolds Averaged Navier-Stokes (RANS) equations. The complex topography of the terrain in the simulation area is included in the model. In addition, this CFD model can track both mixed gaseous species as well as predict the trajectories of individual

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particles (FLUENT Theory Guide). By utilizing these schemes within the CFD model, realistic simulations of aerosol and dust transport can be achieved.

2. Methodology

2.1. Site description

The Iron King Mine Tailings are located in north central Arizona at 34.500° north latitude and 112.253° west longitude with an average altitude of 1436 m above sea level. The topography of the land directly adjacent to the mine tailing impoundment is characterized by rolling hills with the Chaparral gulch bordering the northern edge of the mine property and the Galena gulch bordering the southern edge. Larger mountains are located slightly further away in the surrounding Prescott and Tonto National Forests. It is a semiarid region that receives an annual average of 480 mm of precipitation (NCDC, 2004).

The tailings impoundment rises vertically from the hillside with a rectangular shape and flat top. The tailings material has regions of reddish brown color and consists of gravelly sands and silty sands (Remedial Investigation Report, 2010). The tailings have a loam texture that consists of 34.7% sand, 44.8% silt, and 20.4% clay (Solís-Dominguez et al., 2012). The tailings are encrusted with white efflorescence deposits after rain storms.

2.2. Observations

Since December 2011, the Iron King Mine tailings have been equipped with two 10-m height towers fitted with meteorological instruments and dust monitors. Each tower has three anemometers located at 10 m, 3 m and 1 m heights. The north tower is equipped with all cup anemometers; while the south tower has a 3-D sonic anemometer located at 1 m above the ground. Additional meteorological instrumentation was used to measure wind direction, temperature, relative humidity, soil moisture and temperature. Three TSI DUSTTRAK II 8530 dust monitors were fitted to each tower at 10 m, 3 m, and 1 m heights. Each dust monitor utilizes an omnidirectional inlet that has a particle size cutoff of 27 μm aerodynamic diameter. Fig. 1 shows 4 days of observations taken during 2012, including the 3-m height wind speed and direction, as well as the 1-m height DUSTTRAK data. As expected, there is a noticeable diurnal pattern in both in wind speed and direction with wind speed increasing during the morning hours and turning to calm conditions in the early evening. The dust monitor data show a similar diurnal pattern with higher dust concentrations as the wind speeds increase during the day. Occasional peaks in dust concentration during the day are due to brief wind gusts or top soil perturbations.

The region's climate is characterized by two windy and dry seasons during spring and fall. This is ideal for producing aeolian dust. In this study, we focus on the 2012 spring windy season which we define as being from April 1st to June 30th. The end of the spring windy season coincides with the start of the North American Monsoon when convective outbreaks can cause localized heavy rains that increase soil moisture, which inhibits dust emission.

The average wind rose of the 2012 spring windy season can be seen in Fig. 2. The wind rose was produced using the 10 m anemometer daylight observations (8^{00}–20^{00} h local time). The dominant wind direction for all wind speed observations are Southerly, Southwesterly, Southeasterly and Northerly. The northerly winds tend to be very low speed and occur during the overnight hours. When we take into consideration only wind speeds exceeding 4 m/s southerly wind direction dominates with 36% occurrence, while 85.2% of wind speeds that exceed 4 m/s come from one of the four wind directions: southeast, south, southwest or west. These observations were used in conjunction with the EPA AP 42 wind erosion model (EPA, 1988) to physically constrain the emission scheme that was used in the CFD species transport model.

2.3. Emission scheme

The emission model used to estimate wind erosion of the mine tailings comes from the EPA AP 42 report (EPA, 1988). The friction velocity is estimated from the near-surface logarithmic wind profile (Eq. (1)), where $u_{(z)}$ is the wind speed (m/s) at height z, K is the von Karman constant, u^* is the friction velocity (m/s) and z_0 is the roughness height (m). The friction velocity is a measure of the shear stress exerted on the surface, and when this shear stress

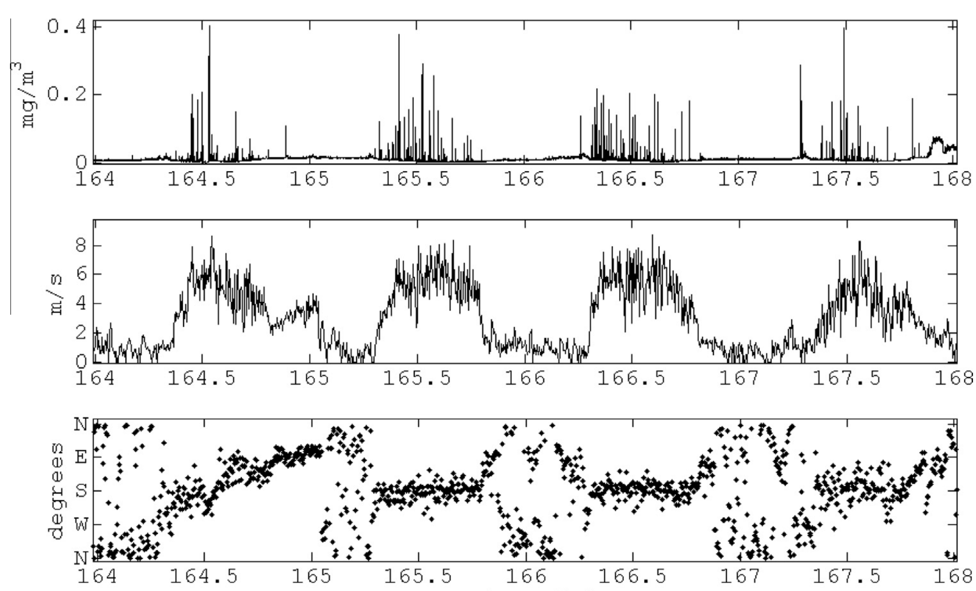

Fig. 1. Time series of observations taken from the eddy flux tower located directly on the tailings from June 13th to June 17th, 2012. The top plot is the 1 m height dust concentrations with a 10 s sample frequency. The middle plot is a time series of the 3 m height wind speed with a 5 min sample frequency. The bottom plot is the corresponding wind direction. The x axis represents time in days with integer values corresponding to midnight.

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