Visualization of Air Pollution caused by a Wildfire

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1. Abstract

The smoke from a wildfire significantly affects our lives even when the location of the fire is far away from where we live. Last year, the smoke produced by the Camp fire and Woolsey fire impacted the air quality of all California and neighbor states, leading potential health hazards to residents lived far from the fire. Moreover, the air pollutants produced by a wildfire consist of different mass which will have different effect to human body, a.k.a. PM 2.5 and PM 10. Therefore, it is also useful if a tool can show the movements of all different particles. To avoid the potential risks, it is important for people to know how the smoke will spread out before a fire occurs. In order to understand the smoke dispersion, we propose an application to visualize air pollutants which were emitted from a wildfire. In our application, if there is a fire on the map (users can put a fire on the map), it will illustrate the motion of particles which has negative influence for the human body for the next 7 days. With this application, residents in any area can learn how a smoke will affect their lives if a wildfire occurs.

Key words: Wildfire, Air pollutants, Visualization

Figure 1. The devastating wildfires burning in western Canada and the northwestern USA are contributing to poor air quality conditions, sparking air quality advisories throughout British Columbia and the northwestern United States. [9]

2. Motivation

Last year, Camp fire and Woolsey fire devastated California dramatically. They burned over 250,000 acres causing over 20,000 structures destroyed and 470 people injured or deaths. Moreover, the air pollutants generated by these fires were spread out over California and neighbor states and put residents which lives far away from the fires at-risk for health hazards from smoke inhalation especially for people with heart or lung disease, older adults, and children should reduce prolonged or heavy exertion. Figure

1 shows the dispersion of smoke caused by several wildfires. How and where does the smoke go will be a significant problem for residents in different areas.

Research into the long-term health effects of large wildfires is still new. But a growing body of science shows how inhalation of minuscule particles from wood fires can nestle in the folds of lung tissue and do harm to the human immune system [5]. Considering the smoke damage to people lives away from the fire location, if there is a tool that can predict and visualize fire smoke dispersion before a fire burns, they will learn what the density of smoke in each area is and have more time to prevent from health risks induced by smoke. Therefore, we would like to propose a visualization to predict the spread of air pollutants caused by a wildfire.

3. Related work

The fire-generated pollutants consist of particulate matter, carbon monoxide, atmospheric mercury, ozone-forming chemicals, and volatile organic compounds. In this project, we focused on toxic pollutants (particulate matter) which can affect human directly. Especially when particles are less than or equal to 10 micrometers in diameter, since these particles small enough so that they can get into the lungs causing potentially serious health problems. The indicator PM 2.5 and PM 10 are used to show the density of particles with diameter less than 2.5 µm and 10 µm respectively.

These particles with different mass also known as mass-dependent or inertial particles will mainly be spread out through wind. Visualization of particle-based flow has been widely explored in experimental and computational fluid dynamics [2]. Most of the researcher only focus on massless particles, since the vector field will directly correspond to the tangent of massless particles' trajectory, to visualize the vector filed, massless particles become a useful tool. However, in real-world applications, the mass of a particle will significantly impact the behavior of a particle in a flow field. In our case, the particles emitted from a fire will be carried by the wind but not directly follow the wind direction because of the effect of their mass.

To calculate the trajectories of inertial particles, derived from Maxey-Riley equations [4], Crowe et al [1] lead to the following equations of particle motion:

$$\begin{aligned} \frac{\mathrm{d}\mathbf{x}}{\mathrm{d}t} &= \mathbf{v}(t) && \text{with} \quad \mathbf{x}(0) = \mathbf{x}_0 \\ \frac{\mathrm{d}\mathbf{v}}{\mathrm{d}t} &= \frac{\mathbf{u}(\mathbf{x}(t), t) - \mathbf{v}(t)}{r} + \mathbf{g} && \text{with} \quad \mathbf{v}(0) = \mathbf{v}_0 \end{aligned} \qquad (1)$$

Where u(x, t) is a time-dependent flow field, v is the current particle velocity, g is a gravity vector, x_0 and v_0 are initial particle position and velocity, and r is the particle response time which is characterized by the diameter d_p and density ρ_p of the particle, and the viscosity μ of the surrounding fluid:

$$r = \frac{d_p^2 \, \rho_p}{18 \, \mu} \quad (2)$$

To simplify the equation for our application, refer to GÜNTHER [3], first, we assume the particles are rigid spheres and the density of the surrounding air is far smaller than the particle so that the buoyancy can be ignored. Moreover, we neglect collisions between particles and let the vector filed will not be affected by the particles.

4. Research approach

The main goal of this project is to predict the spread of smoke from a wildfire. Ultimately, a tool to visualize the movements of all pollutants emitted in a fire is provided to help residents understand the potential health risk on a specific area. The details of the propose application is described in the following sections.

4.1 Data and Parameters

The wind data is 6-hourly prediction produced by the Global Forecast System (GFS), operated by the US National Weather Service. Forecasts are produced four times daily and made available for download from NOMADS. For parsing the data to the desired format, I adopt the library from cambecc [6] to transfer the raw data to a json file. For the experiments, the datasets are fixed starting from February 27th to Match 5th. The wind data will be loaded into the webpage and used to build the wind field to calculate the movements of all particles.

PM2.5 and PM10 are standard particles of air pollutants. To calculate the movement of particles, in this paper, I assume the particles have diameter with 2 µm and 10 µm respectively and the density of particles is 1650 kg/m^3 based on the definition from Yang et al [8]. Since this project focuses on air pollution, the surrounding environment will be air, thus the viscosity was set to $\mu = 1.532 \times 10^{-5}$ kg/(ms).

4.2 Movement of inertial particles

The movements of particles with different mass are calculated by equation (1) and (2) with the parameters provided in the previous section. At each time step, we update the differences of the location and the velocity of each particle by the result of previous calculation. The velocity of a particle is based on the original velocity and the wind velocity at a time T. Therefore, the particle will be moved by the combining velocity. For particles with different diameter, the velocity differences are different. Hence, we can see the trajectory of particle with diameter 2 µm is different from the trajectory of particle with diameter 10 µm in the simulation result.

4.3 Smoke Visualization

The visualization of the map is showing in Figure 2. In this project, the initial view will be located at California, the user can change the location by dragging the map and modify the view size by zooming bottoms on the top left.

Figure 2. The initial map visualization locating at California

The particles with diameter 2 µm are drawn on the map with color brown and color blue is used to represent the particles with diameter 10 µm. The opacity is used to represent the density of particles. Initially, we release 20 particles for each type of air pollutant located around the fire location to the wind field with initial velocity = 0. By the calculation of equation (1) and (2), we update the location and velocity of particles for each time step. All the particles releasing at the same time are used to draw a polygon to represent the area that will be affected by these particles. After several iteration, the application generates new particles starting from the fire location. Figure 3 shows a 7 days simulation result with a fire occurs on the map.

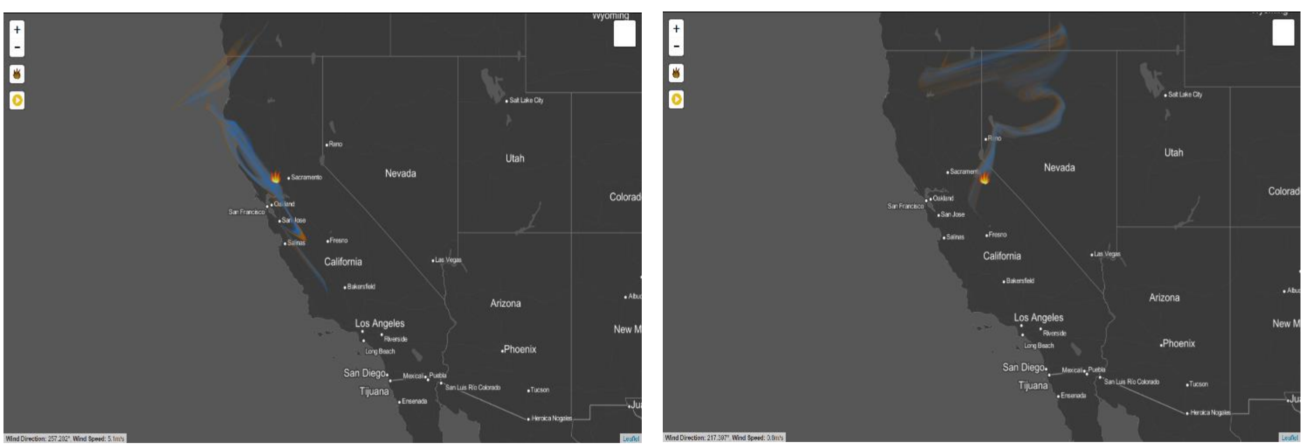

Figure 3. The prediction of smoke dispersion when a fire exists

We also provide a function to observe smoke movements when multiple wildfires happen on the map. The prediction result is showingn in Figure 4. This function helps on studying the interaction behavior of smoke dispersion between wildfires at different place.

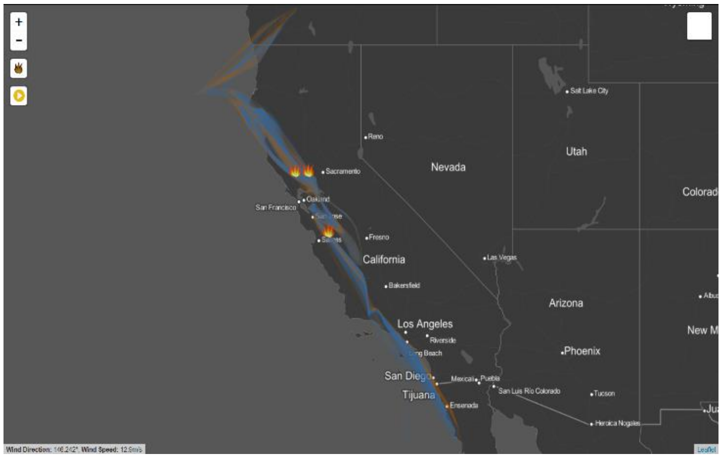

Figure 4. The prediction of smoke dispersion when multiple fires exist.

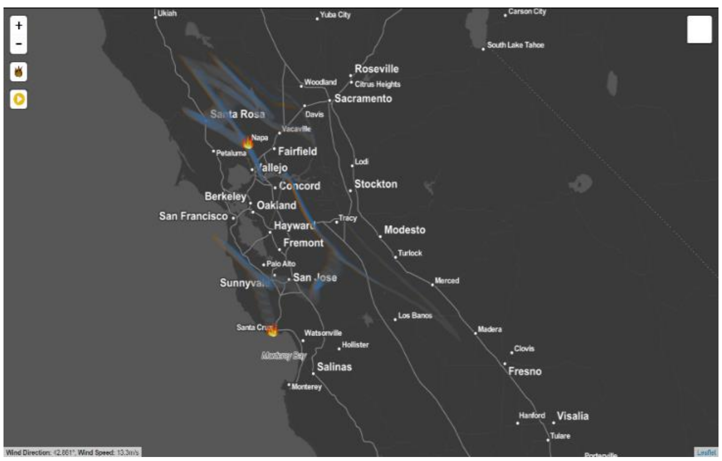

Figure 5. A simulating result of smoke dispersion on a different view.

4.4 System functions

On the web application, the following functions are provided for helping people to observe the spread of wildfire smoke. By using these functions, users can move the map to the area they are interested, set up to 7 fires on the map at the same time, and observe the simulating result of the spread of smoke generated by those fires. All buttons of the functions on the map are shown in the Figure2.

Zoom	By the zoom button in the top-left, users can change the view size to show the area they are interested. Figure 5 shows a simulation result with a view which is different from the default. Note: The simulation will stop when a zoom event is detected.
Drag	By drag the map, users can move the view to show the area they are interested. Note: The simulation will stop when a zoom event is detected.
Fire	By clicking the fire button, users can put a fire or multiple fires on the map by clicking any place on the map. By clicking a fire on the map, users can remove a fire from the map
Simulate	By clicking the play button, the application will start simulating the result of smoke dispersion by the fires on the map

5. Conclusion

The propose web application provides an interface to help people on learning the smoke dispersion of a wildfire. It visualizes the movements of air pollutants emitted by a fire and shows two main pollution particles with different colors which allows users to know what kind of particle might be carried to the area they live by the wind. It also simulates the spread of smoke for 7 days providing more information for people on understanding the flow of air pollutants.

By the provided web application, users can easily learn how the smoke will spread out when a fire occurs on the map and they also can know what kind of particles emitted by a wildfire will be disseminated to the area they live by the wind. With the information they receive, they can prepare to avoid any risks that are caused by the smoke.

6. Future works

The data used in the web application is fixed on a specific range. To aim on helping people to understand the potential risks caused by smoke, it is essential to have a real-time predicting wind data for the future days. Therefore, we will focus on getting the real-time data to improve the information the application provides.

To better get insights on the effect of smoke, it is also helpful to provide the historical data of the past wildfires. Therefore, to improve the application, we can add a function to allow users on observe how smoke spread out with a wildfire happened in the past.

Moreover, it is difficult for people to know where has a higher chance to have a wildfire. Therefore, it is essential that our application can predict the potential fire locations and provide the prediction results to the users to help on observing the potential risks they might encounter in the future.

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