Extreme Wildfire Events Data Hub for Improved Decision Making

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List of Acronyms

ECMWF	European Centre for Medium-Range Weather Forecasts
EWED	Extreme Wildfire Events Data Hub for Improved Decision Making

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Executive Summary

The main task of this deliverable was to enable our 3D simulation tool MicroHH to simulate wildfires as observed in the field. The starting point of this work was a simulation code that is designed for simulating the atmospheric boundary layer (the lowest, turbulent level of the atmosphere) and we have extended this code by enabling the option of adding localized sources of heat, water, and smoke with source strengths resembling what is observed in the field. To do so, we had to make critical adjustments to the model code. After implementing those, this setup has proved to be successful and is now used for the research on extreme wildfires that will ultimately lead to deliverable 4.3. The simulation code MicroHH is freely available at https://github.com/microhh/microhh, and its documentation at https://microhh.readthedocs.io .

1. Introduction

In EWED, 3D simulations of the dynamics of wildfire plumes are used to aid interpretation of wildfire observations from the surface and from soundings. For this task, the Wageningen group uses the MicroHH code [1], a computational fluid dynamics code designed to simulate the atmospheric boundary layer. MicroHH has been used in the past to study the turbulent atmosphere in many configurations, including convective plumes [2], and cloud formation during the day [3] as well as in nighttime conditions [4].

MicroHH is generally used in combination with the $(LS)^2D$ tool [5] which enables the user to automatically generate boundary conditions from ECMWF ERA5 data, a global archive of reanalysis weather data, to resemble the weather at any location for a given date.

The only missing element to simulate wildfire plumes, is to provide the model with surface conditions that represent the temperature and moisture fluxes and smoke production that originate from a wildfire plume and enter the atmosphere. In this report, we will explain how we have done so, describe where the software can be found, and how a wildfire case should be set up, and show a few figures to demonstrate the method.

2. Implementing a wildfire plume into the existing model

2.1. Enabling MicroHH to run simulations of wildfire cases

Wildfire plumes can be implemented with a varying level of complexity, from using prescribed fluxes, to a fully coupled fire spread model. In EWED, wildfires will be implemented as prescribed fluxes of thermal heat, moisture, and smoke (currently as a passive tracer). By doing so, the simulations will be set up to follow what has been observed at the ground by the firefighting teams, to reproduce the vertical structure of the atmosphere as measured by the radio soundings released into the plume.

In principle, using this setup, the latest release of the MicroHH code (2.0.1) has all infrastructure for the simulation of wildfire plumes. In the process of setting up these simulations, we had to make several changes to the model code to prevent the model from becoming unstable or crashing:

1. **Apply smoothing to the transition zone between wildfires and background.** The large wildfire sensible heat fluxes (often exceeding 100 kW/m^2) next to a background flux of approximately ~100 W/m^2 provide a source of instability to the model, as horizontal gradients of temperature cannot be computed in an accurate way anymore. For that reason, we ensure that the transition between fire and environment is smooth, using at least 5 grid points in the transition.

2. **Prevent the model from crashing in the moisture thermodynamics under high temperatures.** MicroHH evaluates for each grid point whether saturation occurs, and if so, converts water vapor into liquid water. As this is a costly procedure in which complex functions need to be evaluated that provide how much water the atmosphere can contain at a given temperature, we use fast numerical approximations for those complex functions. We discovered that our function does not behave well under high temperatures: it wanted to condense water as the function went out of range. We have fixed this problem by clipping the temperature if it goes out of range. As we know for sure that water does not condense at these temperatures, there is no impact on the physics of the simulation from doing this.

2.2. Instructions for setting up and running a wildfire simulation

To run a simulation with a wildfire, users need to go through the following procedure:

1. **Install MicroHH.** MicroHH can be downloaded from https://github.com/microhh/microhh. The latest release (in the main branch) is enabled to run wildfire plumes. Extensive installation instructions and instructions how to setup up cases are found at https://microhh.readthedocs.io. Example cases are found in the `/cases/` directory, including an idealized wildfire in `cases/drycblles` and the Santa Coloma case in `/cases/santacoloma_fire`.

2. **Select the day and location (in latitude and longitude) of the wildfire.**

3. **Choose the desired domain size and grid resolution.** Performing wildfire simulations is an optimization process between domain size and resolution. On the one hand a large enough domain needs to be simulated to capture the background turbulent flow and have sufficient space for the plume outflow, and on the other hand, the resolution needs to be high enough to resolve the near-surface plume and flow characteristics. In practice, we use domain sizes in the order of ~20 x 10 x 6 km^3, and grid spacings of 15 x 15 x 15 m^3 and run the simulation for several hours. This combination of domain size and grid spacing is computationally costly, and require supercomputer access, or a high-end workstation GPU to run.

4. **Download the necessary input data using the (LS)^{2}D tool or prepare input files manually.** The standard option is to automatically generate the initial and boundary conditions from ERA5 data using

(LS)²D, but if a more idealized study is desired to study plumes in a simpler setting, also manual generation can be used. (LS)²D and extensive instructions are found at https://github.com/LS2D/LS2D.

5. **Run the MicroHH simulation for at least two hours prior to the wildfire.** This is to ensure that the background atmospheric boundary layer is fully developed with realistic fields of wind, temperature and humidity, resembling the correct level of ambient turbulence.

6. **Save the state as the starting point for the wildfire simulation.** It is important and handy to save the state of the atmosphere at the start of the wildfire as experiments with varying surface fire properties can be performed.

7. **Enable the wildfire by adding 2D fields of prescribed surface fluxes of temperature, water, and smoke that resemble the ground observations to the background surface fluxes of those variables.**

8. **Determine the desired output for plume and flow statistics and visualization.** This consists of area-averaged statistics of atmospheric variables and cross-sections (in any desired plane) and full 3D fields.

9. **Run the wildfire plume simulation and store the desired output.**

With the steps above, we have been able to perform simulations of multiple fires, that are elaborated below.

3. Some examples of wildfire plumes

To demonstrate that the steps above provide credible wildfire plumes, we provide here three examples, the Santa Coloma de Queralt (dry) plume in Catalonia on the 24th of June 2021 (Figure 1. Simulation of the Santa Coloma de Queralt fire during the 24th of June 2021Figure 1), the Varnavas dry plume in Greece on the 11th of August 2024 (Figure 2), and the Tortosa plume with pyrocumulus formation on the 28th of May, 2024 (Figure 3) cases observed by respectively the Catalonian and Greek firefighting teams. These cases span different types of plumes, including one with moist convection, demonstrating that our simulations can reproduce pyrocumulus clouds. In case of the Santa Coloma fire, we show the collected sounding (Figure 1, right plot) by the Catalonian team next to the model results, demonstrating that the simulations can capture the plume rise. Note that the colder near-surface temperatures in the soundings are because the sounding is released upstream of fire plume and only enters the plume ~300 m above ground.

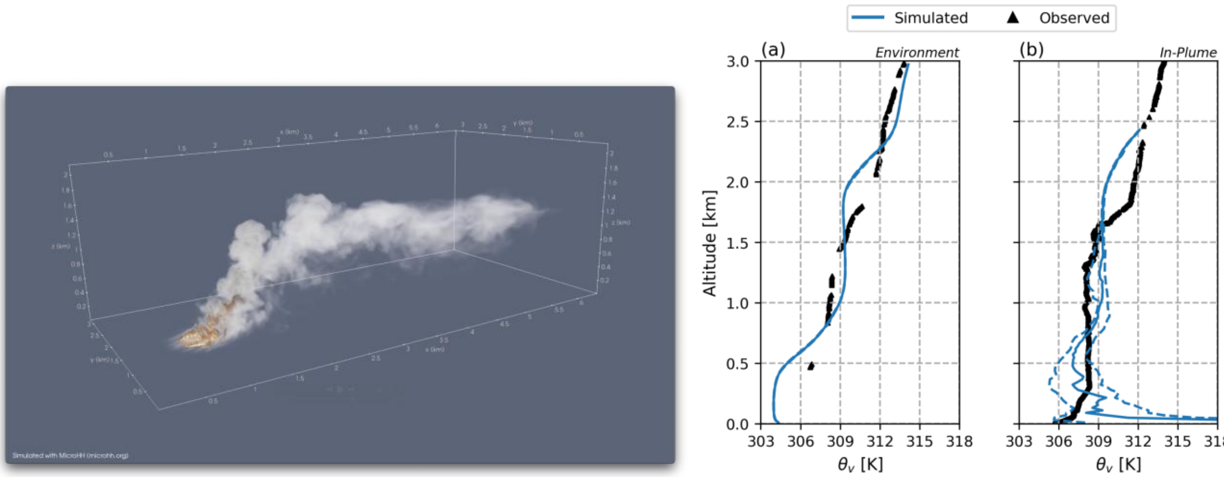

Figure 1. Simulation of the Santa Coloma de Queralt fire during the 24th of June 2021. Left panel shows the smoke concentration using a non-linear colour scale, right panel shows the observed environmental and in-plume sounding compared to the simulation.

In case of the Varnavas fire (Figure 2), we show the sounding in combination with the wind evolution in the case. Here it is shown that the model displays a low-level jet (peak at 1200 m with 20 m/s) that is also captured in the sounding.

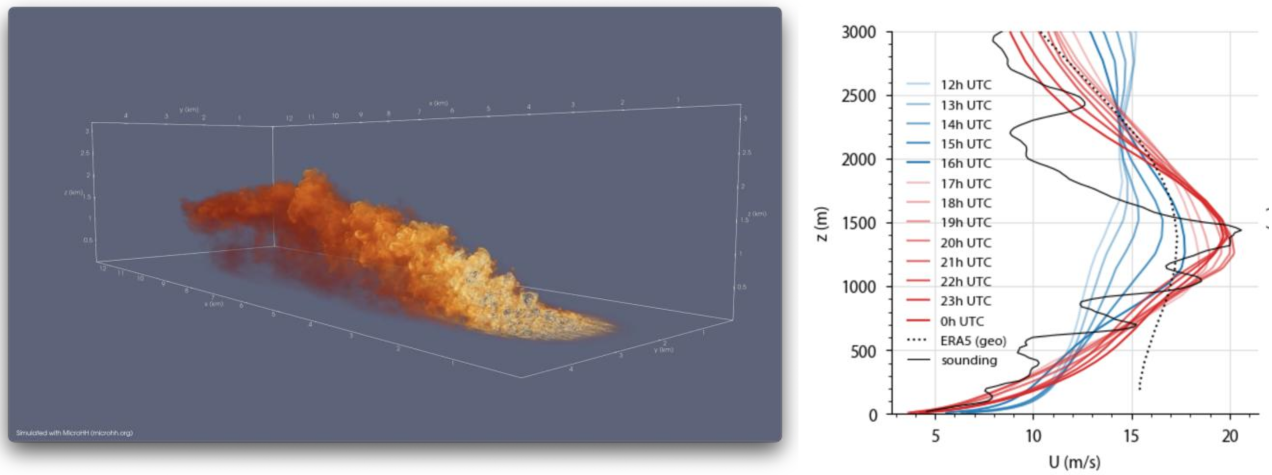

Figure 2. The flat structure of the high-wind speed Varnavas plume during the 11th of August 2024. This visualization (left) highlights the smoke plume and shows the tight connection to the surface of this plume. In

the right panel, we find the hourly wind profiles compared against the sounding taken during the fire (at 23 UTC).

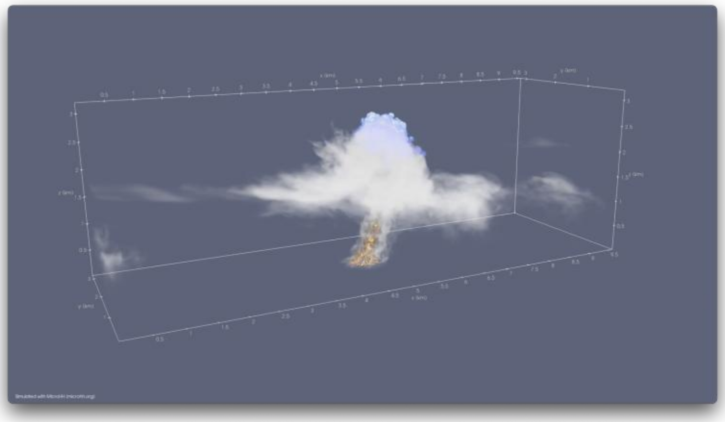

Figure 3. Pyrocumulus formation in the Tortosa fire (28th of May 2024). Left is the simulated plume; right is a picture from the field for comparison.

For the Tortosa fire, we present a visual comparison between the simulated plume and the observed plume in the field (Figure 3). We show both the simulation (left panel) and the observed wildfire plume (right) at the moment that the pyrocumulus clouds forms, leading to an accelerated vertical rise.

4. Conclusions

By completing this deliverable, we have prepared and tested a model setup for our simulation code MicroHH that can simulate wildfire plumes of under a wide range of fire intensities and atmospheric conditions, including moist convection, and we have provided the instructions how to download the code and how to set up a wildfire case.

5. References

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