Vorticity-Driven Lateral Spread Ensemble Data Set

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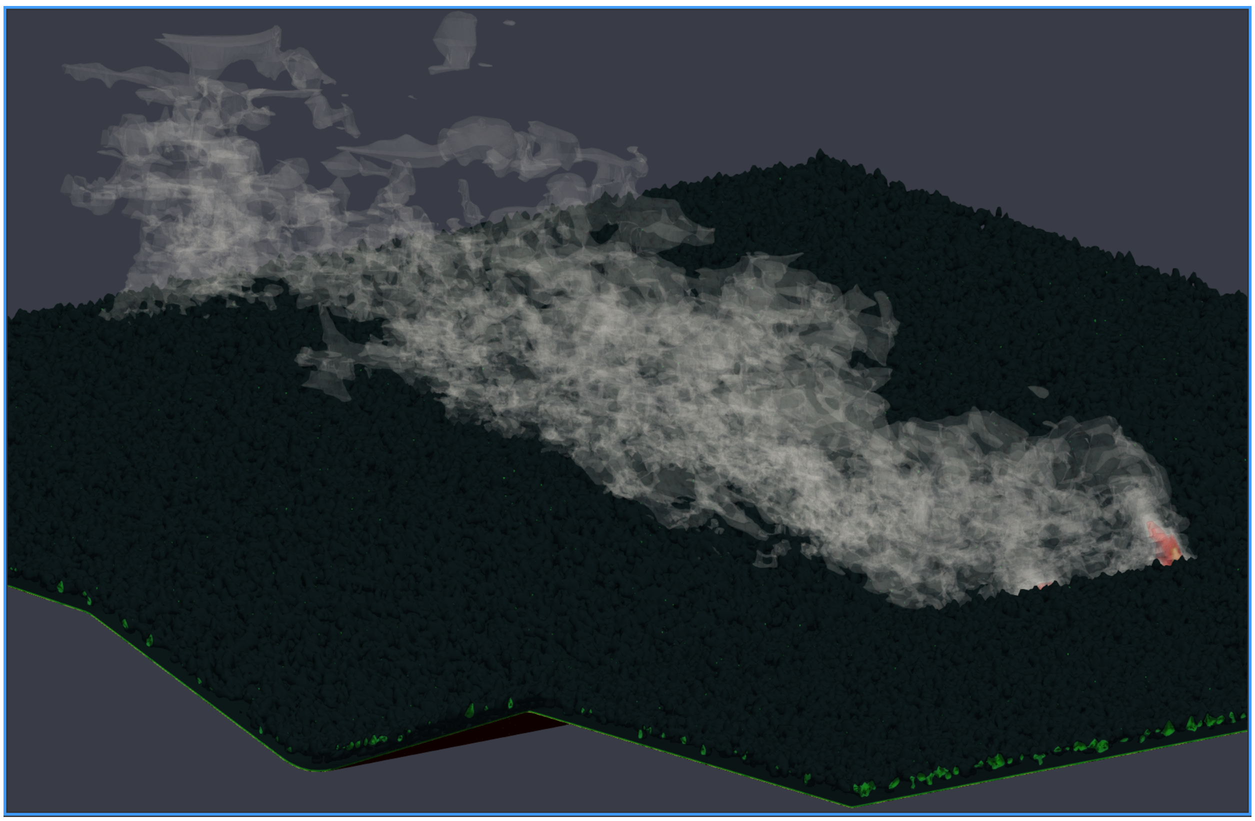

Figure 1: A valley wildfire modeled using topography from the Los Alamos Los Conchas Fire.

1 Introduction

This ensemble data set presents the study of wildfires, and more specifically, the phenomena known as vorticity-driven lateral spread (VLS) [1], in wildfires of mountain and canyon topographies. The emergent behavior of wildfires results from an interaction between a complex set of physical and chemical phenomena, including combustion, atmospheric dynamics, and a multi-phase turbulent flow. These nonlinear interactions, and corresponding range of scales of processes influencing wildfires, contribute to the challenges of understanding the behavior of wildland fires. However, it is essential that we better understand the cause and effect relationships that connect the fire environment to fire behavior. The fire environment includes vegetation and atmospheric conditions, factors that largely impact the movement of a wildfire. It also includes the topology of the landscape, which has a massive impact and can contribute to the acceleration, deceleration, or redirection of a fire.

To understand wildfire behavior, scientists use coupled fire/atmosphere models such as LANL's HIGRAD/FIRETEC, which combines two codes: Higrad, an atmosphere hydrodynamics model, and Firetec [2, 3], a multi-phase fire-physics model. This computational fluid dynamics (CFD) system models the fire in conjunction with three-dimensional fuel structure (vegetation), atmosphere, and topography. The CFD model is based on the solution of conservation equations of mass, energy, momentum, as well as chemical species equations and turbulence. The initial simulation set includes quantities transported through an Eulerian mesh, but this tool can also capture the transport of fire brands through Lagrangian transport.

In order to shed light on some aspects of VLS behavior, we produced a suite of simulations by running Higrad/Firetec in mountain and canyon scenarios. Two main types of topographies are used in this simulation set: mountain topographies with different shapes at the ridgeline, and a canyon topography that models the shape of a northern New Mexico canyon. Each of the mountain terrains simulations were performed with ignition upwind and downwind of the ridgeline. This has resulted in in headfires (spreading in the direction of the ambient wind) and backing fires (spreading against the ambient wind) moving upslope towards the ridgeline. While the mountain simulations are idealized topographies, the canyon simulation included in the ensemble is modeled after a canyon in northern New Mexico, where a wildfire in 2011 (Las Conchas Fire - https://en.wikipedia.org/wiki/Las_Conchas_Fire) burned hundreds of thousands of acres. Scientists are now asking questions concerning the potential role of VLS in this fire.

This suite of simulation data was produced with the hope of investigating the role of topographic shape on the VLS phenomenology [4]. Vorticity-driven lateral spread (VLS) is a wildfire phenomena involving rapid lateral (cross stream respect to the ambient wind) fire propagation on leeward slopes or behind ridgelines. VLS is driven by the complex dynamic interactions between the fire-induced buoyancy-driven updrafts and topographically-induced flow patterns, specifically the cross stream vorticity or re-circulation on the leeward side of a ridgeline or strong break in slope. More specifically, VLS develops from wind-terrain-fire interactions as the fire-induced updrafts reorient the topography-induced re-circulations creating vertically vorticity, including strong lateral velocities. This drives rapid lateral fire spread across steep slopes in a direction almost perpendicular to the ambient wind direction. This behavior has recently been highlighted as a major factor in several fire blow up events behind ridgelines, but emerging research illustrates that this behavior might also exist in other scenarios such as steep canyons. In order to prepare for and potentially manage such behavior it is important that we continue to increase our of understanding of the environmental factors that affect this behavior and what wind, topography and fuel combinations pose significant risk of VLS occurrence. However, given that VLS is a result of complex interaction between ambient vegetation and terrain-influenced flow and the buoyancy of the fire, untangling and explaining this phenomena provides a particularly interesting challenge for visualization experts.

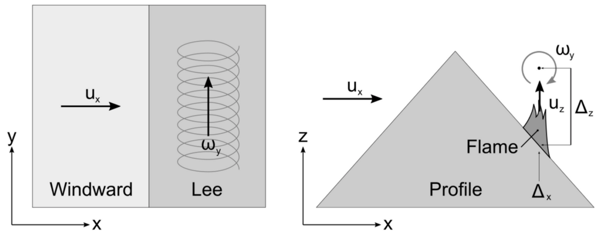

Figure 2: A diagram of vorticity-driven lateral spread. Figure credit Sharples et al. [4]

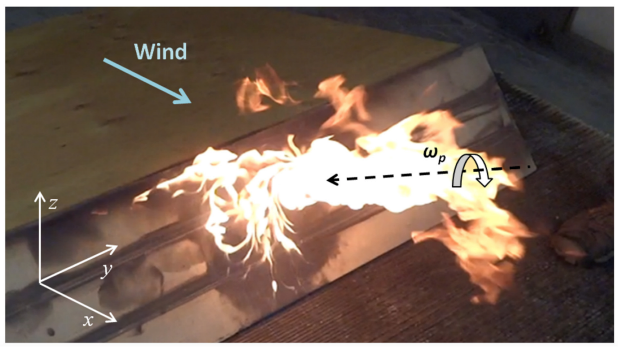

Figure 3: Experimental fire in a wind tunnel showing a fire vortex on the leeward slope of an idealized ridge. Figure credit Sharples et al. [4]

2 Data Set Details

The data for the IEEE SciVis 2022 Contest will consist of multiple time series (each 70 to 100 times steps) of 3D scalar fields on a $600 \times 500 \times 61$ curvilinear grid from coupled Higrad/Firetec simulations [3, 2]. This corresponds to a $1.2meters \times 1meter$ landscape. The z dimension measures the altitude above the lowest point in the domain, approximately $1.5meters$ on a variable resolution grid that extents to $915meters$ above the lowest point in the topography. The terrain-following grid contains three-dimensionally resolved fuels starting from the ground and extending upward. The computational cells will also include information about the atmospheric velocity components, potential temperatures, density of fuel (vegetation), and oxygen concentrations. The number associated with each file divided by 100 represents the time passed since the start of the simulation. Therefore, outputs are in 10 second increments. The fire is generally ignited at about 50 seconds into the simulation (around the fifth output), allowing the wind field to find its balance before the fire starts. Each file is saved in Paraview's *.vts* format.

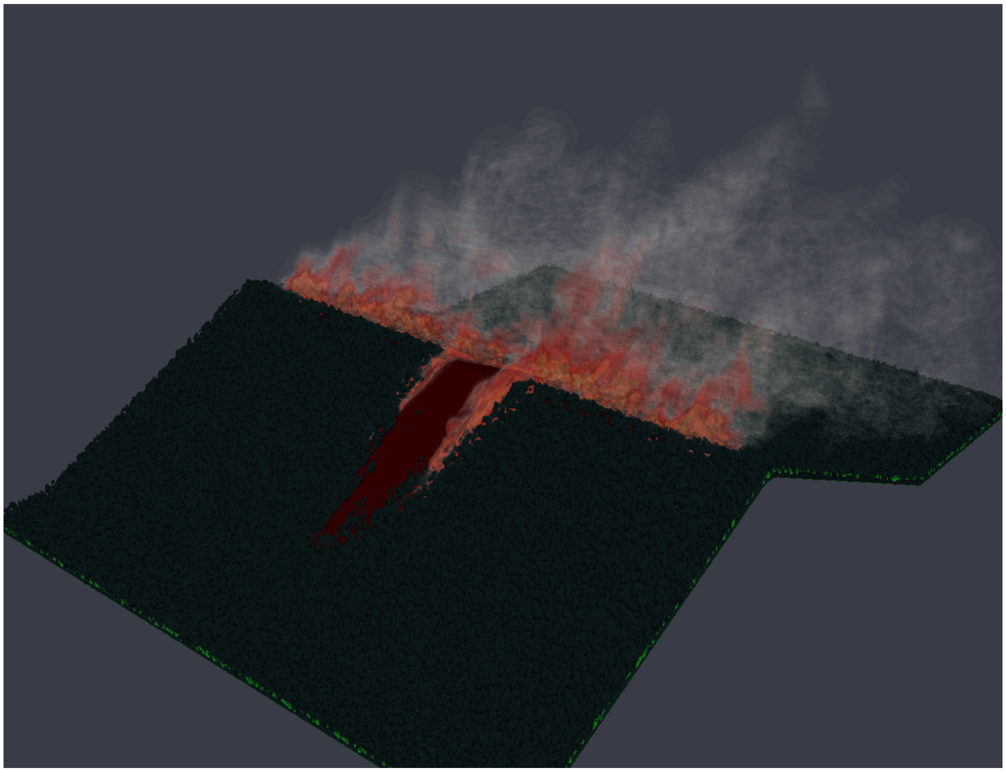

Figure 4: Head curve fire on a mountain topography

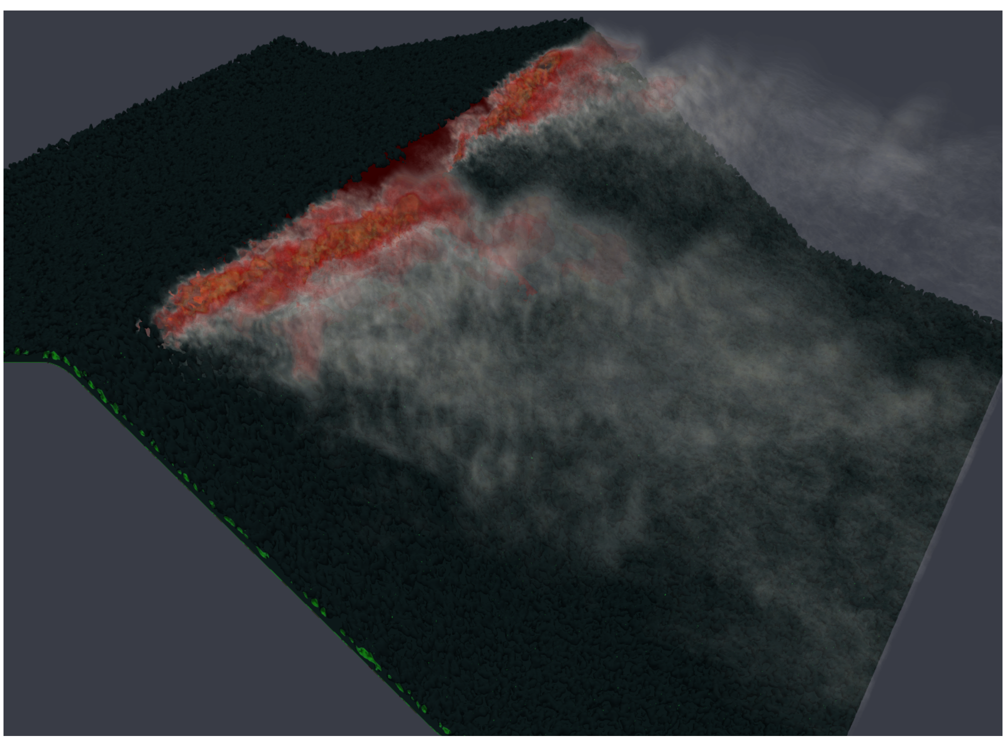

Figure 5: Back curve fire on a mountain topography

2.1 Simulation Naming Details

Simulations names are first tagged with the topographical structure - either *mountain* or *valley*. Mountain simulations are then tagged with either *head curve* or *back curve* to indicate whether the fire starts as a headfire or a backing fire and that the simulation is a part of a suite of simulations exploring the influence of the radius of curvature along the ridgeline. Finally, a numerical value is associated with each simulation - 40, 80 or 320. This value determines the radius of curvature or roundness of the peak of the mountain. A higher value indicates a more rounded ridgeline, resulting in a gentle hill top as opposed to a sharp pointy ridge.

2.2 Scalar Fields

- **O2:** oxygen concentration
- **convht_1:** convective heat transfer (W/m^3)
- **frhosiesrad_1**: fire-induced radiative heat transfer to the fuels (W/m^3)
- **rhof_1:** bulk density of dry fuel (kg/m^3)
- **rhowwatervapor:** bulk density of the moisture released to atmosphere as result of fire (kg/m^3)
- **theta:** potential temperature (K)
- **u:** vector component of wind aligned horizontally in the general direction of the upper level mean wind (streamwise)
- **v:** vector component of wind aligned horizontally perpendicular to the general direction of the upper level wind (crosstream)
- **w:** vector component of wind in the vertical direction

2.3 Hints for Getting Started

What we refer to as fire is the aggregated impacts of heated vegetation (trees, grass, shrubbery) reacting with oxygen (through several chemical reaction steps). As a part of this process what we think of as flame is produced through *luminescent soot*, which contributes to "smoke" as it cools off. Therefore, there is no hard line between smoke and fire, both can be represented using potential temperature (*theta*) parameter. Smoke is captured using values closer to ambient potential temperature (ambient is $300K$) while flame, which burns hotter, is represented with values closer to the range between 400 K and 800 K. It is important to remember that these temperature values are cell averages and not that actual temperature of flame, which is much hotter. In addition, because fire depletes both oxygen and vegetation in its path, consider regions where the oxygen is lower than surrounding areas, decreasing from around 0.205 to 0.13. Also examine regions where the vegetation has changes over time, to identify locations where the fire might have burned it out.

References

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[2] Rodman Linn, Jon Reisner, Jonah J Colman, and Judith Winterkamp. Studying wildfire behavior using firetec. International journal of wildland fire, 11(4):233–246, 2002.

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[4] Jason J Sharples and James E Hilton. Modeling vorticity-driven wildfire behavior using near-field techniques. Frontiers in Mechanical Engineering, 5:69, 2020.