HPC for Wildfire Simulations

An overview of the High Performance Computing rule in simulating wildfires

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Wildfires

Wildfires (forest fires) are driven by complex physical and chemical processes, operating on vastly different scales.

The Interaction between these processes depends on coupling between the atmosphere, topography, fire, and solid fuels (the fire drivers).

It's difficult to predict wildfire behaviours accurately due to our limited understanding for these processes and their interactions.

Yet, there has been a long-standing need to improve our understanding of the fire behaviours in order to predict them.

Wildfire Behavior

From scientific prospective

- Principally concerned with the physical and chemical processes of the fire (flow, combustion, heat transfer) and the associated physical quantities such as temperature, flow velocity, pressure, gas species concentration, mass loss, heat release … etc.)

From operational prospective

- Principally concerned with the ignition of a fire; its spread rate, fire front dimensions and energy released; fire perimeter and its growth, and related phenomena such as crowning, spotting and fire whirl activities.

Wildfire Behavior Modelling

In computational science, wildfire modeling is concerned with numerical simulation of wildland fires in order to understand and predict fire behavior.

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Wildfire modeling attempts to reproduce fire behavior, such as how quickly the fire spreads, in which direction, how much heat it generates … etc.

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In recent years, wildfire models, modelling systems and simulations have been developed constantly and its role have been increased gradually in understanding and predicting wildland fire behaviour.

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This has been a process greatly aided by advances in computer technology and by breakthroughs in our understanding of fire dynamics.

Importance of wildfire modelling

- Aid wildland fire suppression
- Increase the safety of firefighters and the public
- Reduce risk, and minimize damage.
- Protecting ecosystems, watersheds, and air quality.

Wildland fire behaviour models are typically distinguished into

- (1) Empirical models
- (2) Physics-based models
- (3) semi-empirical models

Empirical models

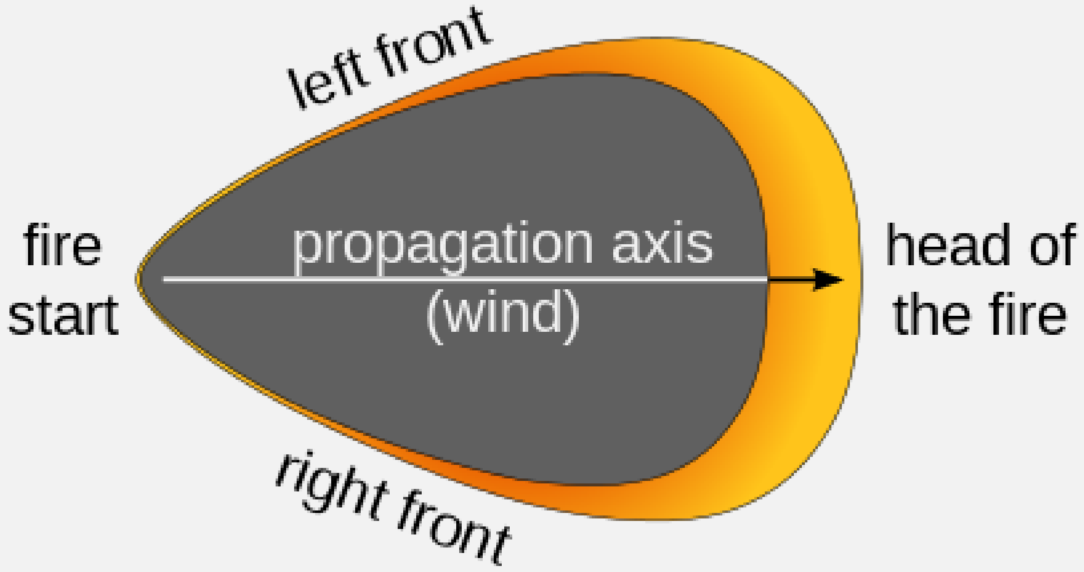
The empirical models rely on experimentally derived relations to predict the fire behaviour.

Mostly so far, empirical models aim to support an operational decision-making process as they are faster to compute and can provide instant information to fire managers.

Started to be developed back into the 1940s and several modeling systems have came along and were in turn used for practical proposes like assessing the effectiveness of fuel treatments or predicting the head fire's spread rate.

Two-dimensional fire growth models such as FARSITE and Prometheus to calculate fire spread and other parameters along the surface using certain assumptions to shape the fire growth.

However, it was pointed out that the operational fire modelling systems currently used to simulate the wildland fires exhibit a significant under prediction bias.

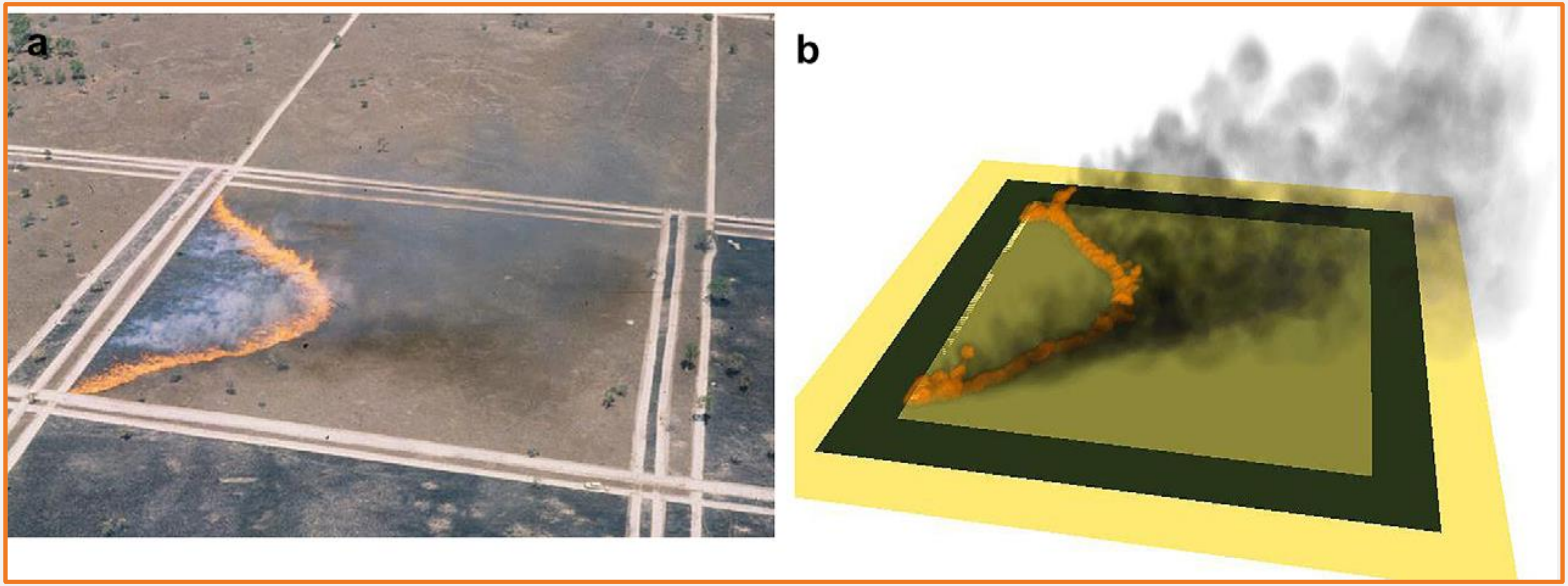


Physics-based models

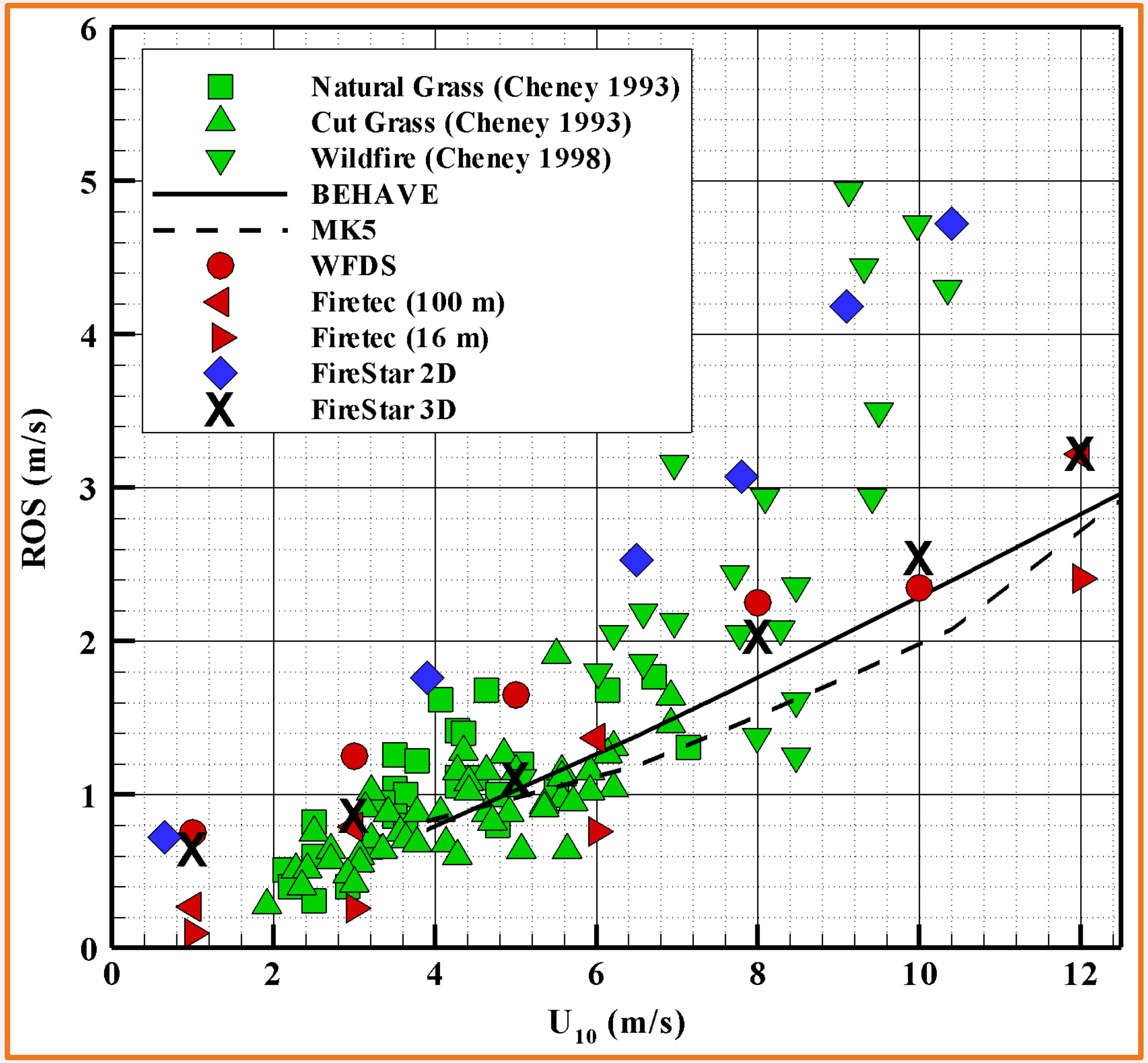
- Physics-based models are primarily developed with theoretical purposes in mind, aiming to better understand the physical and chemical processes that control the fire's propagation.
- Development of the physics-based models began on the 1970s with simplified two-dimensional fire spread models based upon conservation laws.
- At that time, computational resources and numerical methods were not sufficiently advanced to allow three-dimensional, time-dependent simulations of wildland fires.
- With the dramatic increase in the capability of computers and numerical approaches in the last 30 years, there is a better opportunity for the physics-based fire modelling systems to be used.

- But However, the complexity and computational requirements of these modelling systems limit their usage to the scientific research and some management-oriented applications.
- With providing a mega scale computational resources, some of these models may be used to accurately predict a wildland fire behaviour after an extensive evaluation process.
- FIRETEC(2002); the wildland–urban interface Fire Dynamics Simulator (WFDS)(2007) and FIRESTAR(2009) are two examples for three-dimensional, time-dependent simulators that recently developed and used to study wildland fire dynamics.

- Have been applied to better understand the fundamental aspects of fire behavior, such as fuel inhomogeneity on fire behavior, feedbacks between the fire and the atmospheric environment and wildland urban interface fire spread.
- These models join computational fluid dynamics (CFD) models with heat with heat transfer and mass transport models along with combustion chemistry models.
- There is a trend to use these models for more operational and management proposes but with some simplifications.

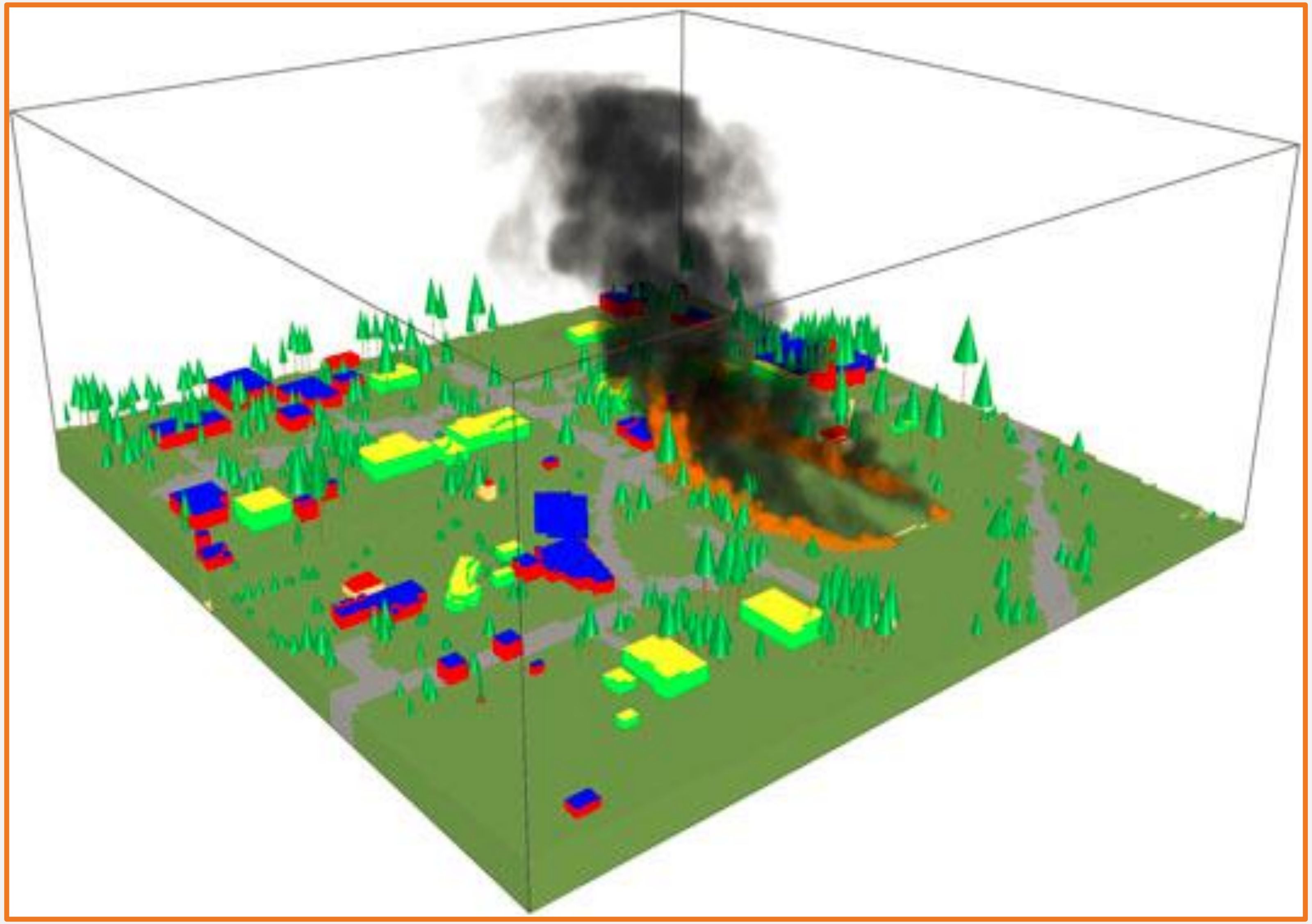


A comparison of observed versus simulated fire behavior (from Mell et al., 2007): (a) oblique aerial photograph of an experimental grass fire in the Northern Territory of Australia (200 by 200 m plot size) and (b) a WFDS visual simulation of the experimental grass fire at the same elapsed time since ignition.

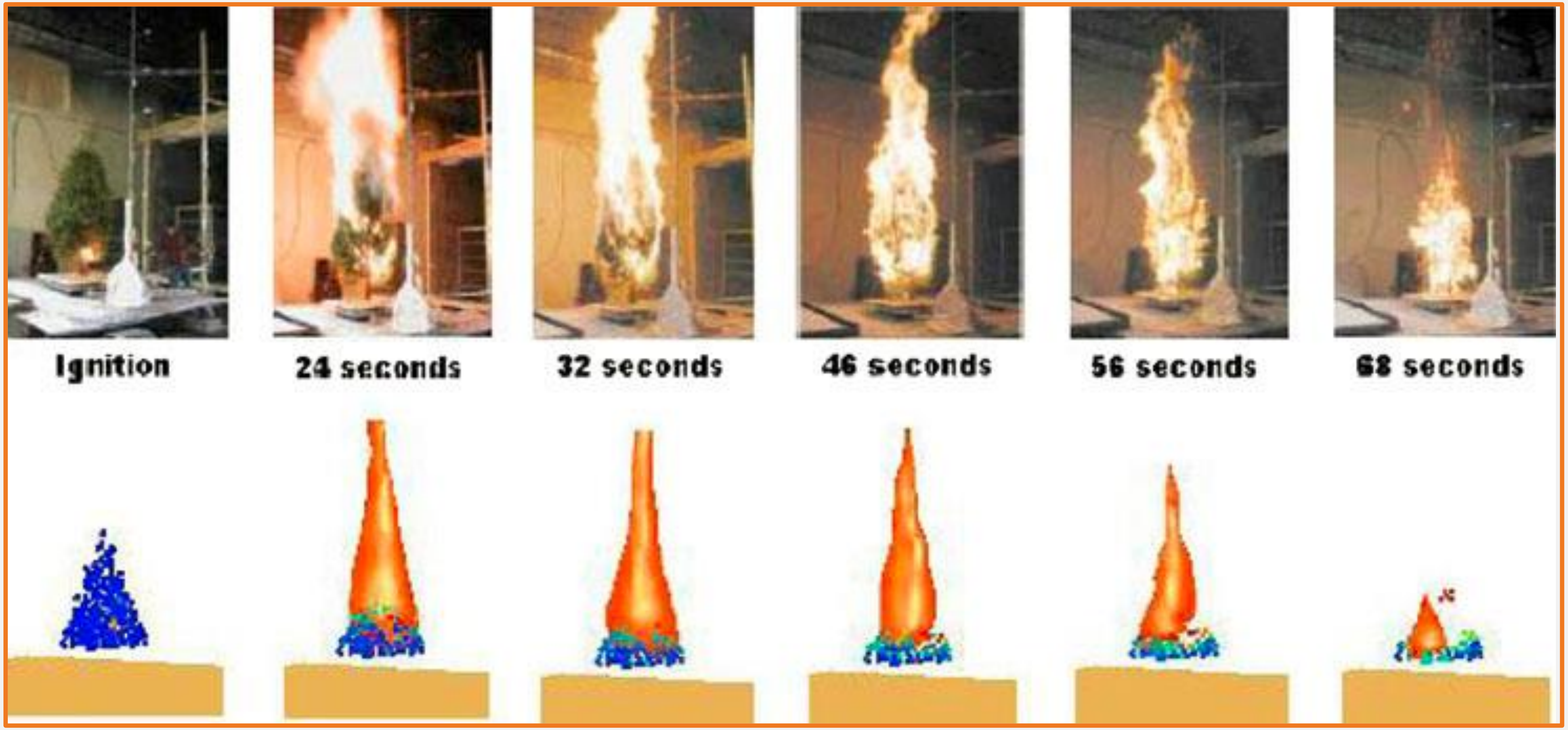


Rate of fire spread (ROS) through a uniform grassland obtained for different wind speeds measured at 10 m above ground. The results of this study (FireStar3D) are compared to the results obtained experimentally (Cheney 1993), and using an empirical model (MK5), a semi-empirical model (BEHAVE), 3D numerical models (FIRETEC, WFDS), and a 2D numerical model (FireStar2D).

(D. Morvan, 2016)



Numerical simulation using WFDS of a surface fire propagating through a WUI community (D. Morvan, 2010)



Experimental fire and simulation using WFDS carried out in a tall Douglas fir (courtesy of W. Mell from BFRL-NIST)

Semi-empirical Models

The semi-empirical model incorporate physics-based models with empirical models to simulate the fire behavior.

Usually the atmospheric wind is simulated using physics-based models (computational fluid dynamics methods) and the rest of the process are simulated with empirical models or a mix between them.

The Coupled Atmosphere-Wildland Fire-Environment (CAWFE) model developed in 2005 and the WRF-Fire developed in 2009 and two examples for these models.

Working with the Fire Dynamics Simulator (FDS) using HPC capabilities

An application for a fire physics-based simulator and the rule of HPC on it

Computational Physics

Computational Fluid Dynamics Methods (CFD) is a branch of fluid mechanics that uses numerical methods and data structures to solve and analyze problems that involve fluid flows.

Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions.

With high-speed supercomputers, better solutions can be achieved for complex simulation scenarios such as transonic or turbulent flows.

The finite element method (FEM) is a numerical method for solving problems of engineering and mathematical physics and is typical used to solve heat transfer, mass transport and fluid flow problems by yielding approximate values of the unknowns at discrete number of points over the domain (a discrete mesh).

Simulation fluid flows classified according to the assumption on the solution into Reynolds-averaged Navier–Stokes simulations (RANS), Large Eddy simulation (LES) and Direct Numerical simulations (DNS)

Simulating wildfires requires solving numerically each of the heat transfer, mass transport and fluid flow problems in addition to the combustion which is a chemistry problem.

Wildland Fire Dynamics Simulator (WFDS)

An open source LES CFD model of fire-driven fluid flow that is currently under joint development by the United States Forest Service and the National Institute of Standards and Technology (NIST).

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It was created with the intention of simulating fires in buildings basically (FDS) and its adaptation to solve wildfires (outdoor/atmospheric) problems remains relatively untested.

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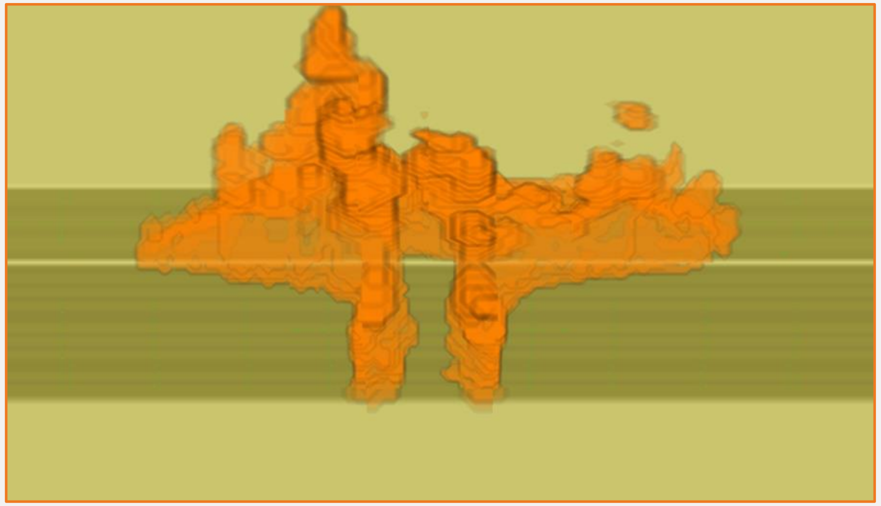
It has proven its ability to predicts wildfire behavior better than other models in some situations.

Small scale fire simulations using WFDS
(an experimental study case)

- Simulating the fire propagation over a hill model placed in a wind tunnel using Navigator
- Ability to predict the “fire channeling”; an extreme fire behavior appears over the leeward side of hills, which cannot be predicted by empirical models.



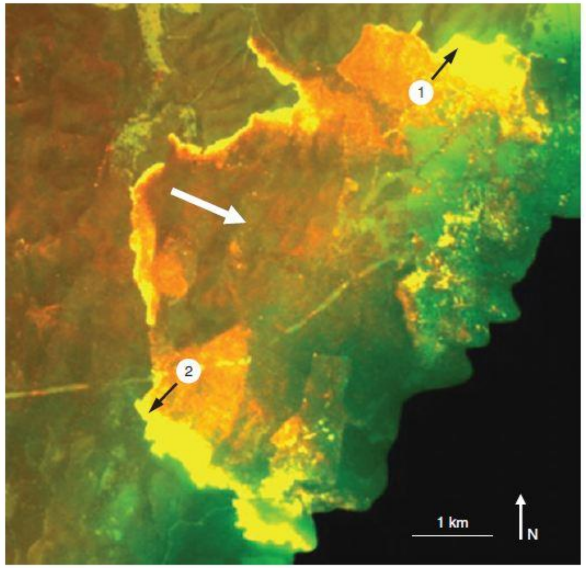
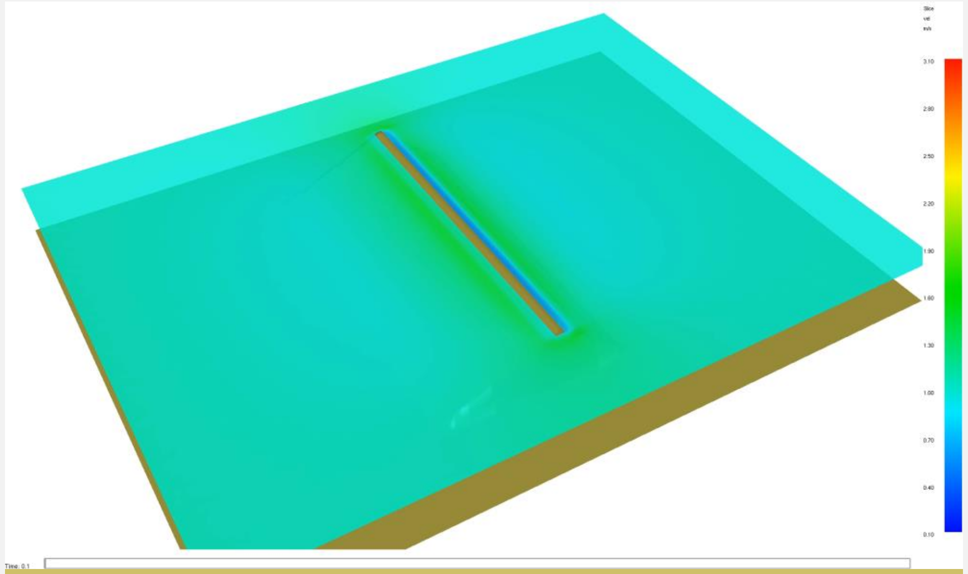


Fig. 11. Multispectral line-scan data for the McIntyre’s Hut Fire (Run 3) showing the bilateral nature of fire channelling. The fire-channelling event near point 1 has spread towards the north-east, whereas the fire-channelling event near point 2 has spread in approximately the opposite direction towards the south-west.

Although that the simulated area is relatively small but it has consumed relatively high computational resources to solve it.

A comparison between different computational resources used to solve 100 seconds of this problem

Computer	CPU	Number of cores	Solving Time
Workstation	2.4 GHz	4 core, 8 threads	39:11:20
Supercomputer (Navigator)	2.7 GHz	24 core	11:25:20



Large scale fire simulations using WFDS
(The case of Pedrógão Grande)

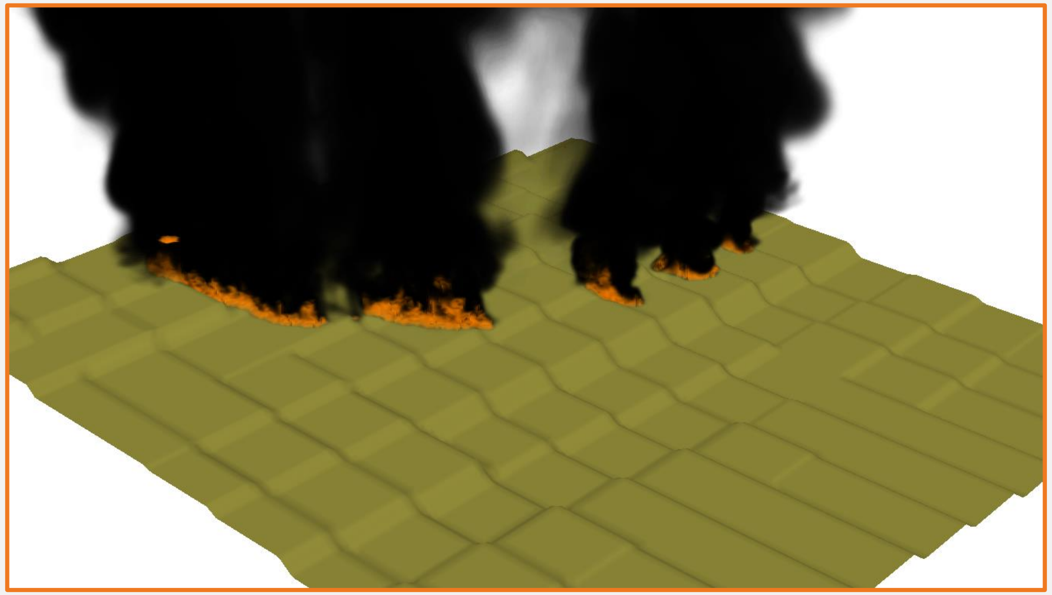
As much as we know, the WFDS have never been used to reconstruct and simulate free-burning wildfires.

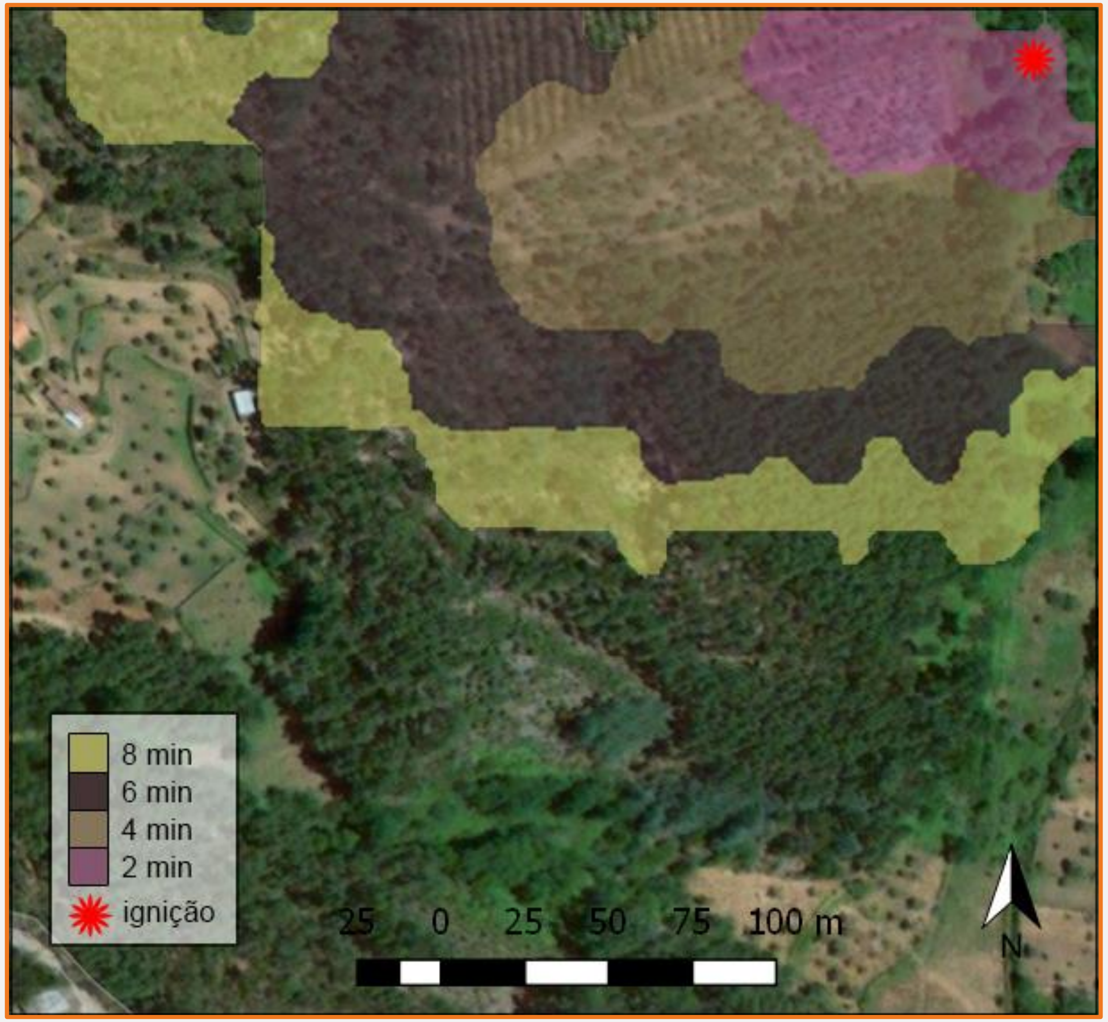
Challenges to simulate wildfires using WFDS (physic-based models):

- Modeling the complex structures of the vegetation
- Difficulty to define the thermal properties of the vegetation
- Modeling the topography
- Optimizing the solution to reduce the solving time (mesh, recourses ..)

On a study to explore the capabilities of the WFDS to simulate free-burning wildfires under extreme conditions, the ignition and the first 8 min after that were simulated using Navigator.

Simulating 8 min clock time of the fire development required around 48 hours simulation time using 1200 CPU core.





Future Prospective For Wildfire simulation

Future Research Work

Better understanding	• Improve our understanding for the wildfire behavior and its associated processes using physics-based models is advantageous and it can be used to investigate phenomena that are difficult to be investigated experimentally.
Developing new models	• Developing new empirical and physics based models that helps to understand better wildfires and predict them for operation proposes.
Evaluation the models	• An extensive evaluation process is needed for several exited models or the new models that will be developed.

Physics-based Models

Are increasingly being utilized to address specific fire and fuel management applications, which is a similar situation to what has occurred some 20 years ago with the empirical models that are utilized in the operational systems today.

This arises, in part, from the pressure stake-holders and funding agencies often put on researchers to produce immediate, reliable results, leading to models the produce management outputs in scenarios they have not been evaluated against.

The obvious question then is: what are the associated safety and environmental hazards if the parameterization in these modelling exercises proves to be wrong?

Empirical Models

Empirical models have the advantages of simplicity and ability to provide instant results.

The empirical models can be modified with some approaches to improve its prediction accuracy without increasing its complexity to still be usable for operational applications:

- Improve our understanding for the fire behavior and to improve the capability of these models to predict the extreme fire behaviors and phenomena
- Using physics-based models to solve part of the processes , like solving the wind spatially
- Use dynamic models that tune its parameters in a way that the results will match the observed situations

The rule of supercomputers

For physics-based models

- Using HPC capabilities is essential to compute the physics-based models

For empirical models

- Using modified empirical models on an operational level will require using HPC capabilities.

For decision-support systems

- Current wildfire management or decision-support systems utilize to supercomputers to run its systems, subsystems and programs. e.g. the European Forest Fire Information System (EFFIS) and the Advanced Fire Information System (AFIS).

IPfire

- The project “Intelligent predictions for wildfires” (IPfire) is an R&D project that’s on the design phase and it incorporates different entities from University of Coimbra and outside it .
- It’s aim is to build a decision support system that integrates several approaches, sources of information and tools using advanced IT technologies to provide instant and crucial information that support the decision-making process before, during and after wildfires operations.
- The system will use Navigator to develop different subsystems to forecast the faire danger, monitor active fires and predict the fire behavior.




Obrigado!