8TH INTERNATIONAL WILDLAND FIRE CONFERENCE | GOVERNANCE PRINCIPLES: Towards an International Framework

Contribution of Science and Technology to Forest Fire Management

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Contents

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1. Introduction

- Forest fires are becoming an increasingly important problem for the society and for the environment in various parts of the World, namely in Portugal.
- We cannot expect to solve this problem but we can attempt to reduce its magnitude and impact through a better and integrated management of its main components.

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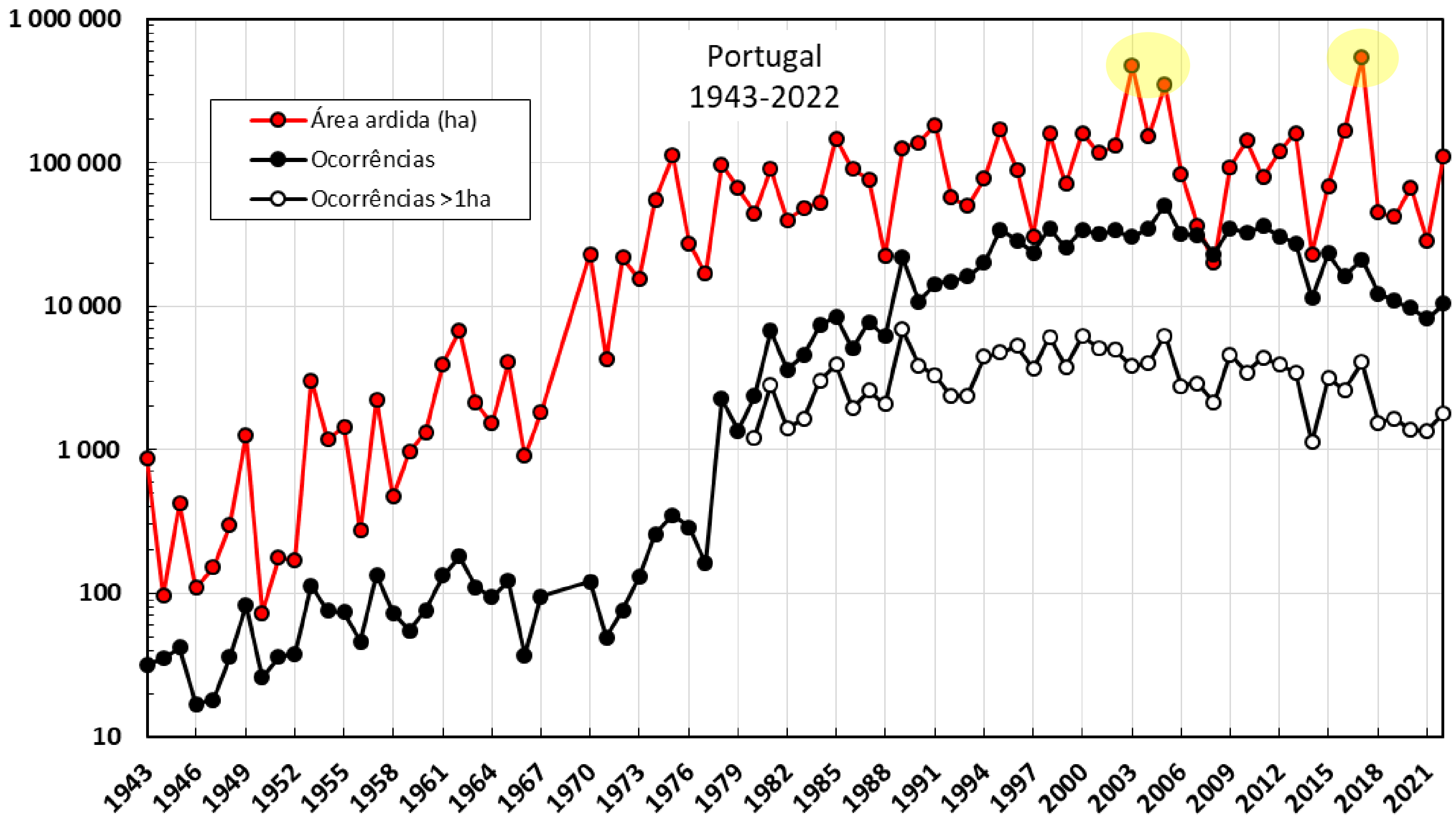
- A better knowledge of the problem, obtained through scientific research, and better management tools developed by technology, are key elements to be more successful.
- This is particularly important for the management of those fires that become very large and threaten the lives of persons.

Anual Number of fires and Burned Area in Portugal

(1943-2022)



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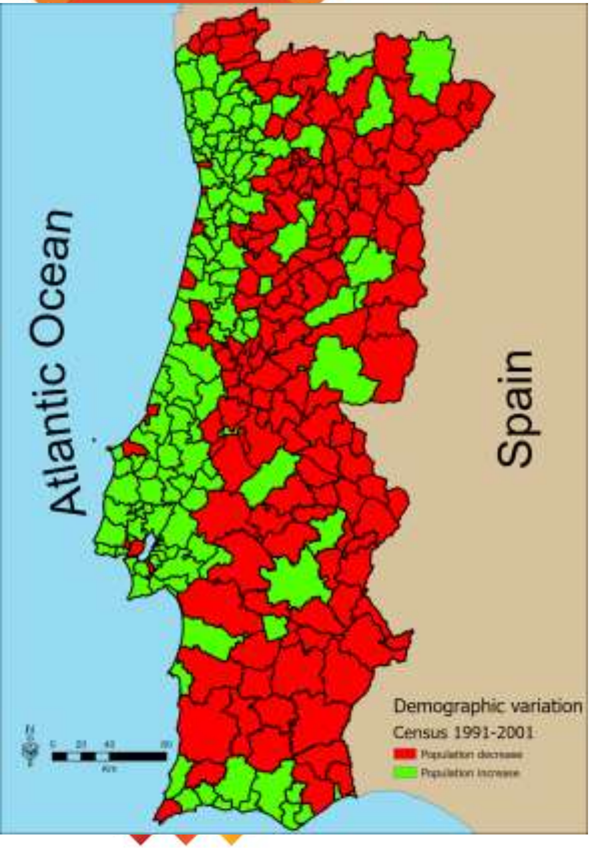
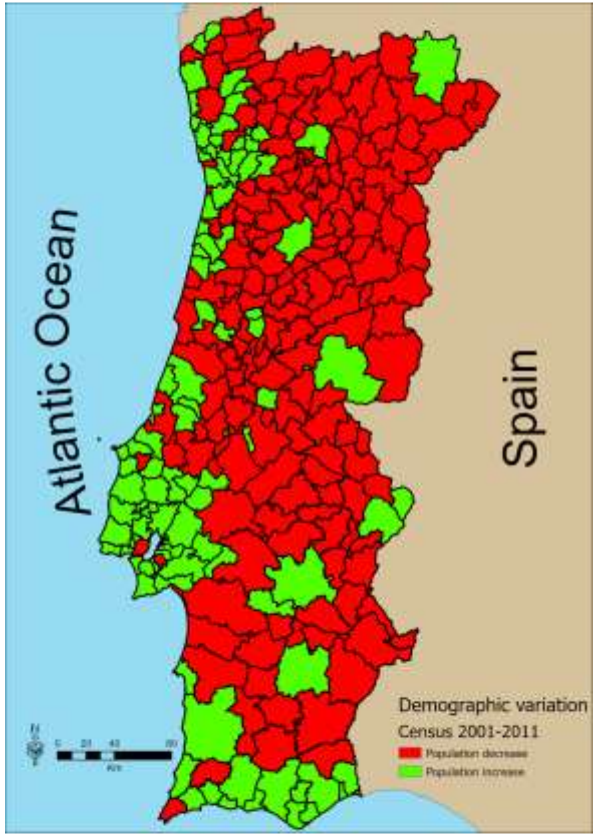
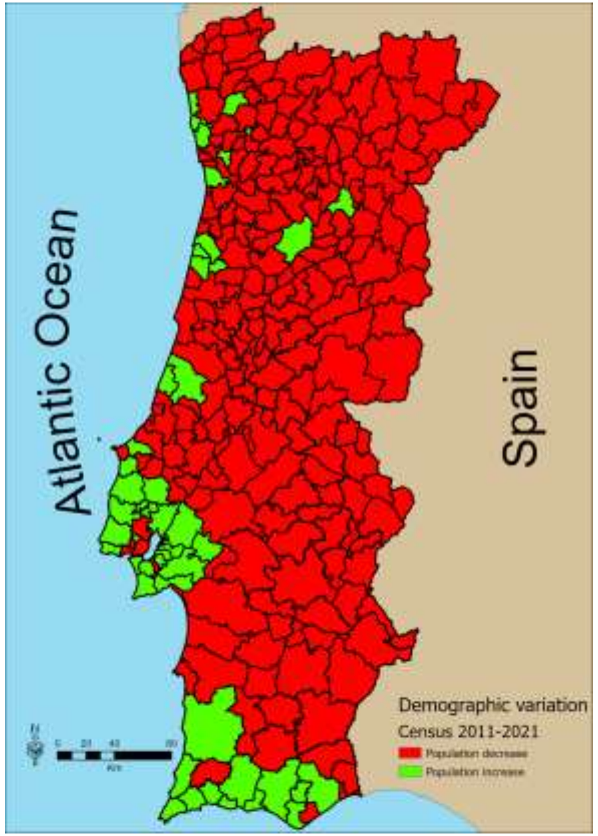
Population change in Portugal (1991-2021)



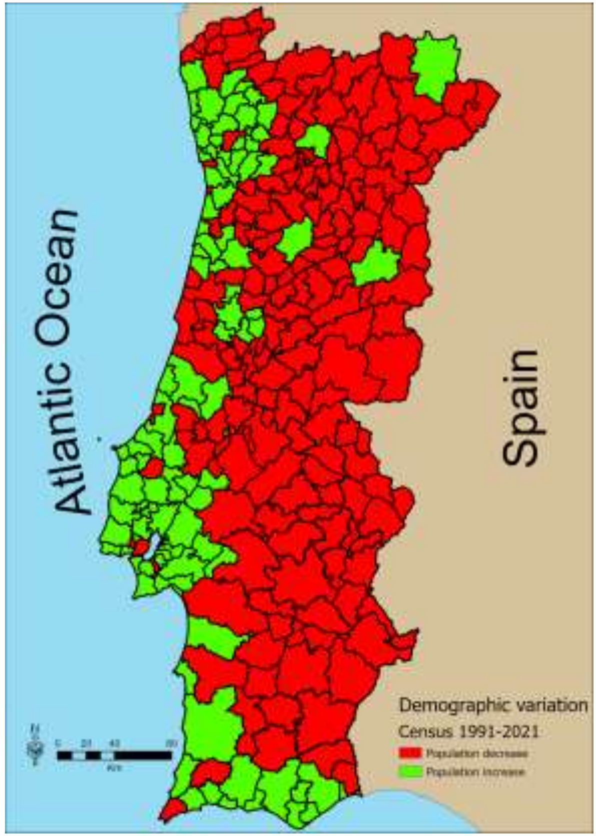
1991-2001



2001-2011

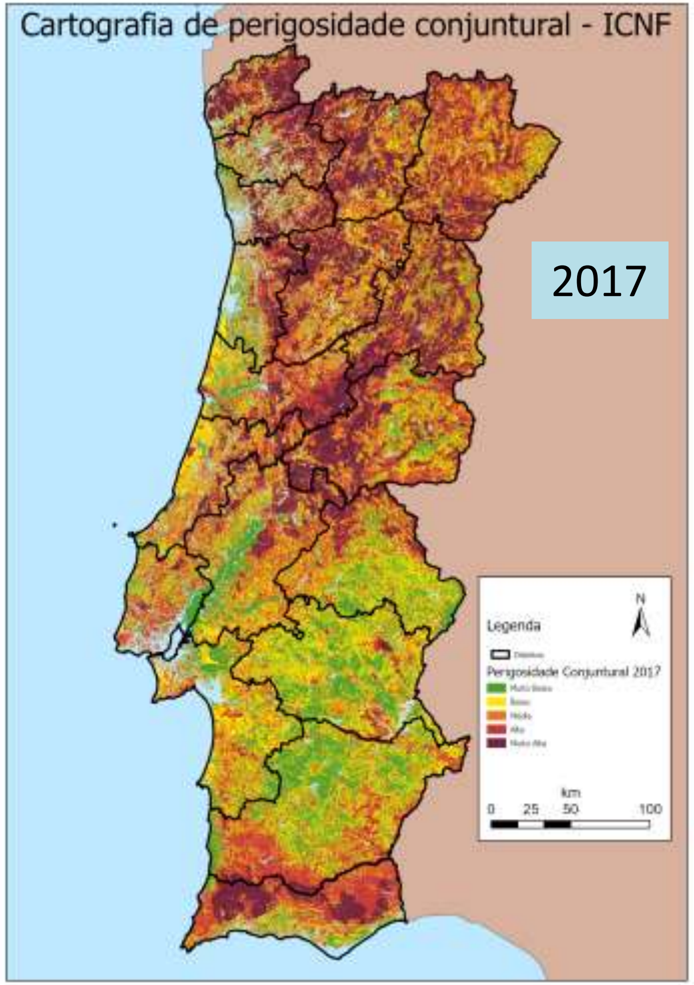


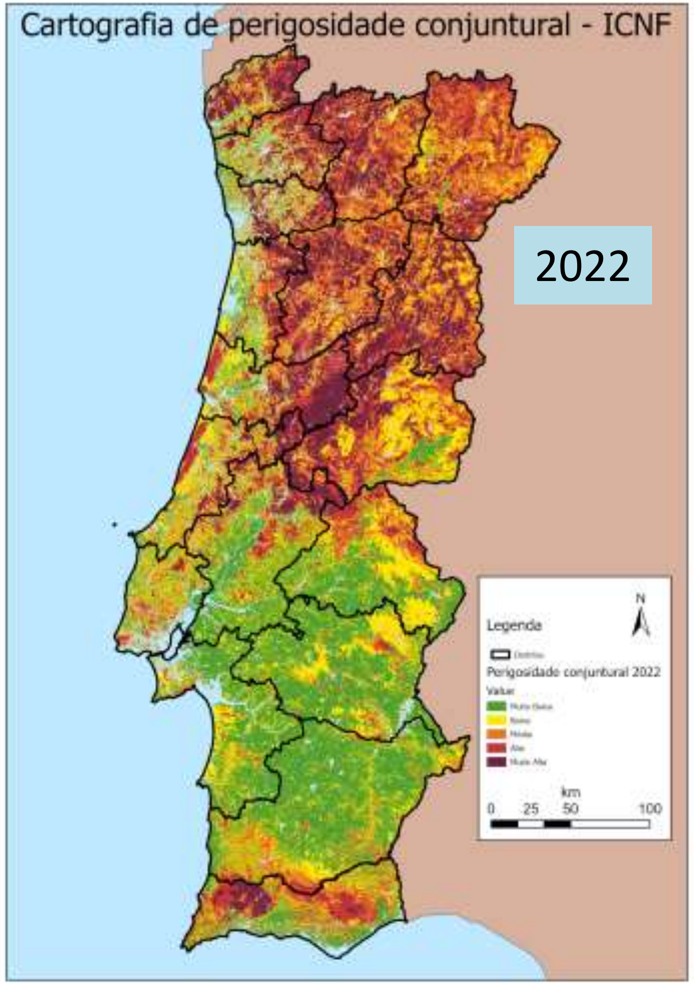
2011-2021

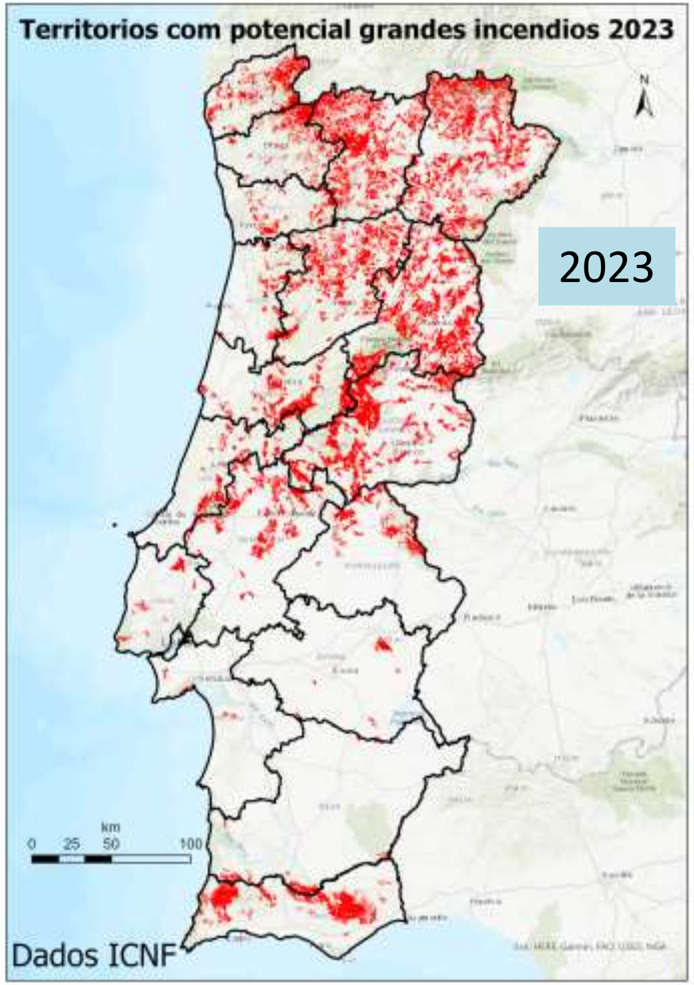


1991-2021

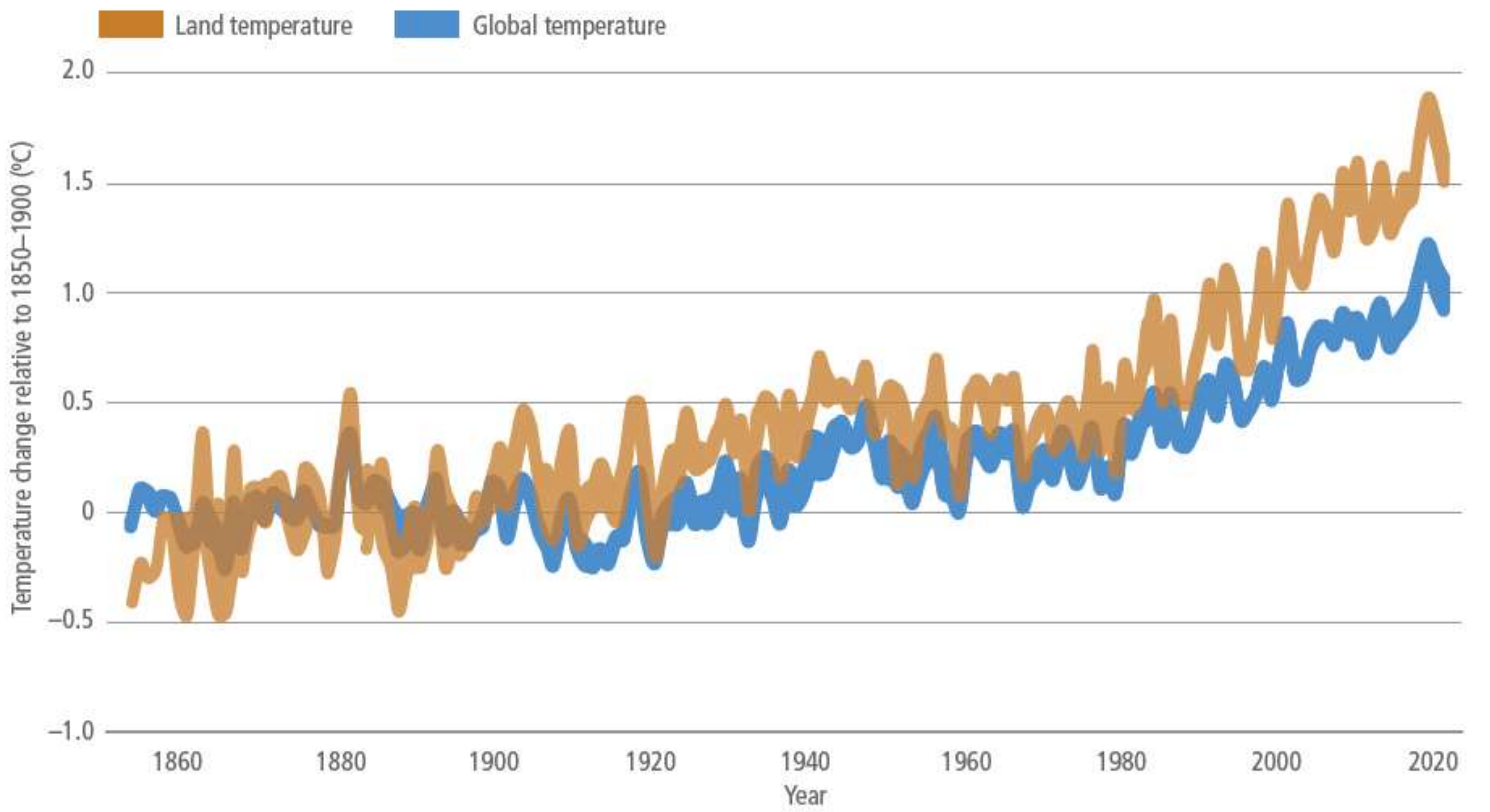
Local risk of fire in Portugal (2017-2022)







Global temperature change



Jia, G., E. Shevliakova, P. Artaxo, N. De Noblet-Ducoudré, R. Houghton, J. House, K. Kitajima, C. Lennard, A. Popp, A. Sirin, R. Sukumar, L. Verchot, 2019: Land–climate interactions. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M, Belkacemi, J. Malley, (eds.)]. In press.

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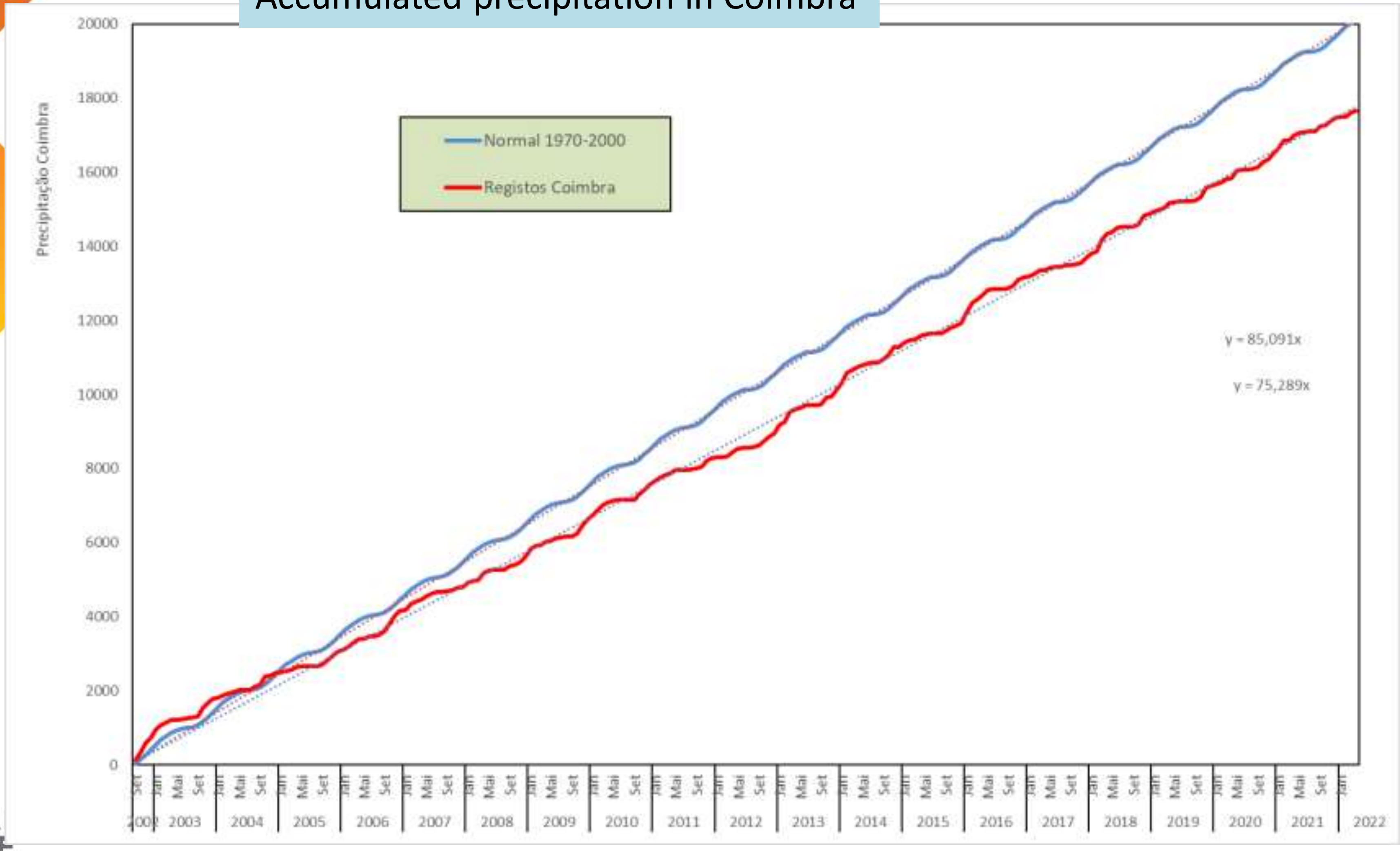
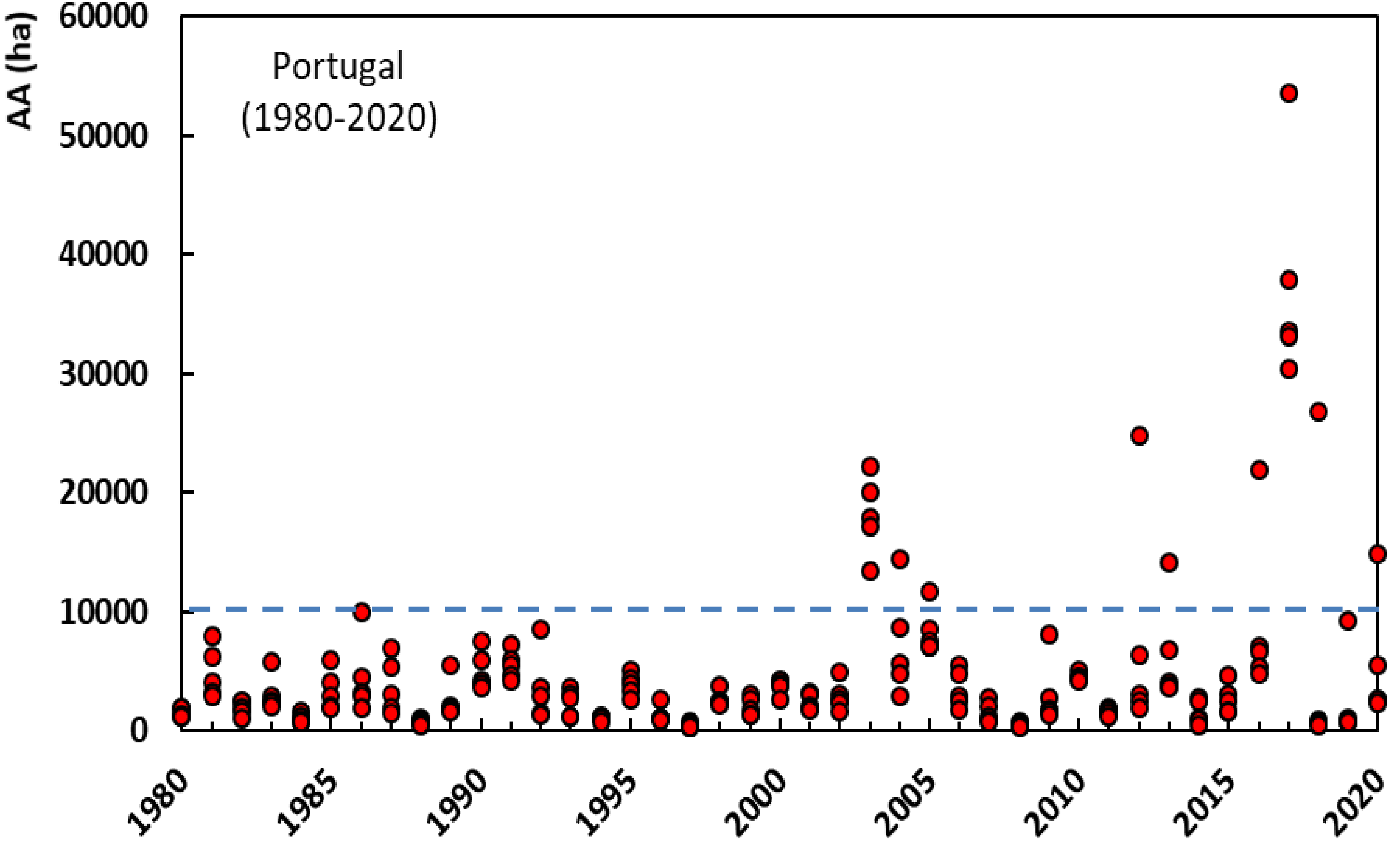
Accumulated precipitation in Coimbra



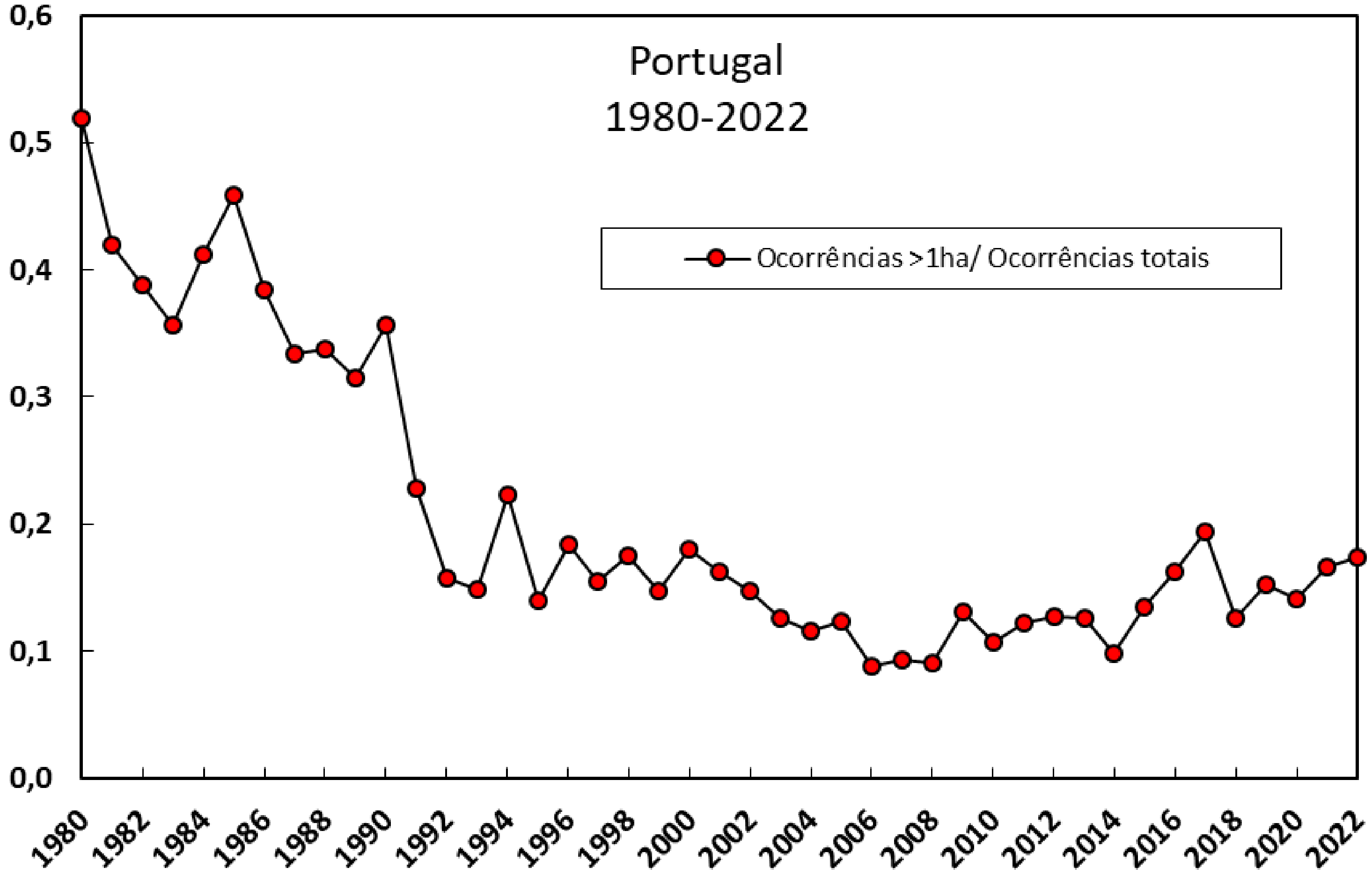
In average we register 12% less precipitation in Coimbra in the last 22 years

The five largest fires in Portugal (1980-2022)



Fraction of initial fires that become larger than 1 Ha in Portugal

(1980-2022)



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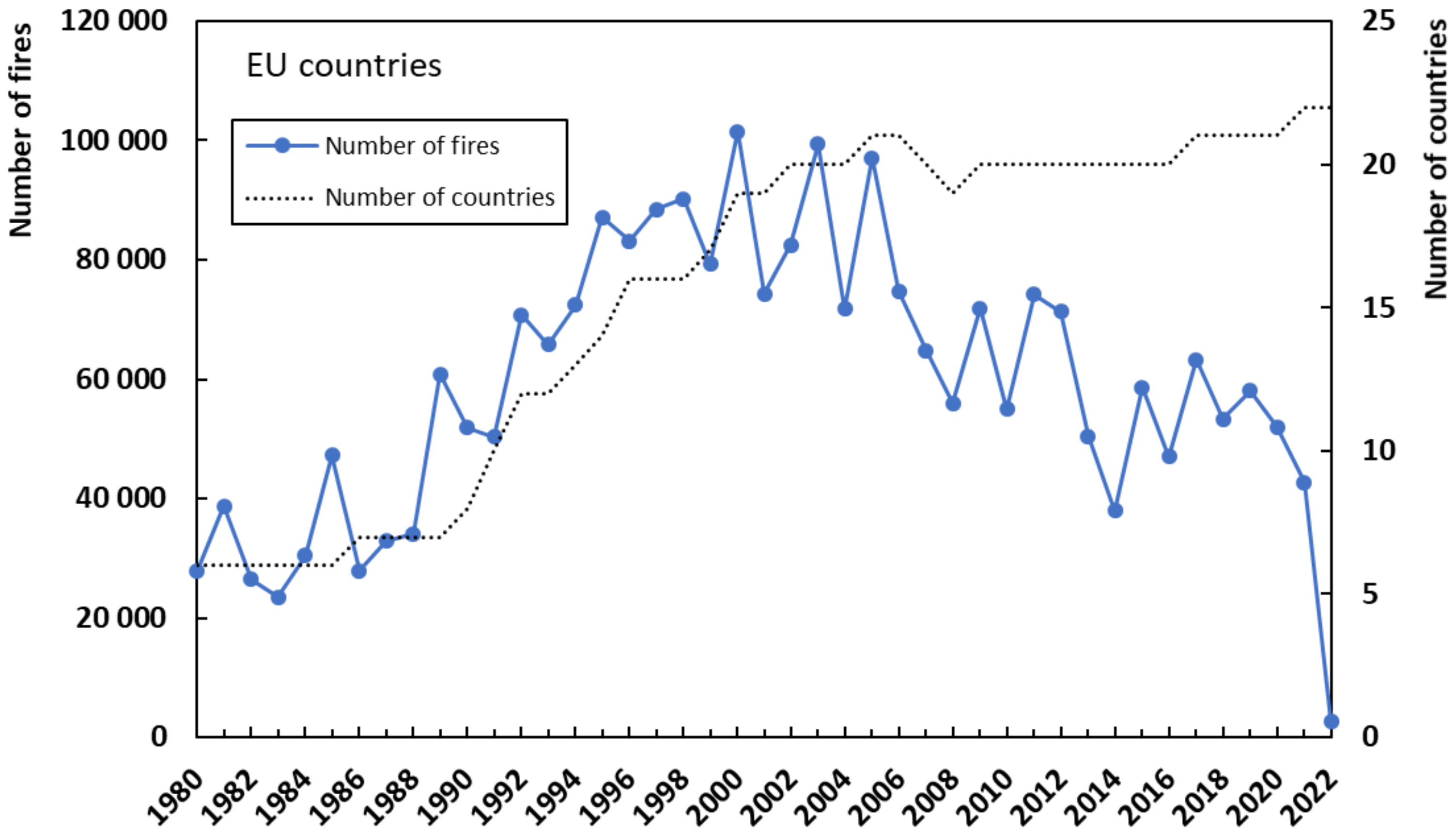
Annual Number of Fires in Europe



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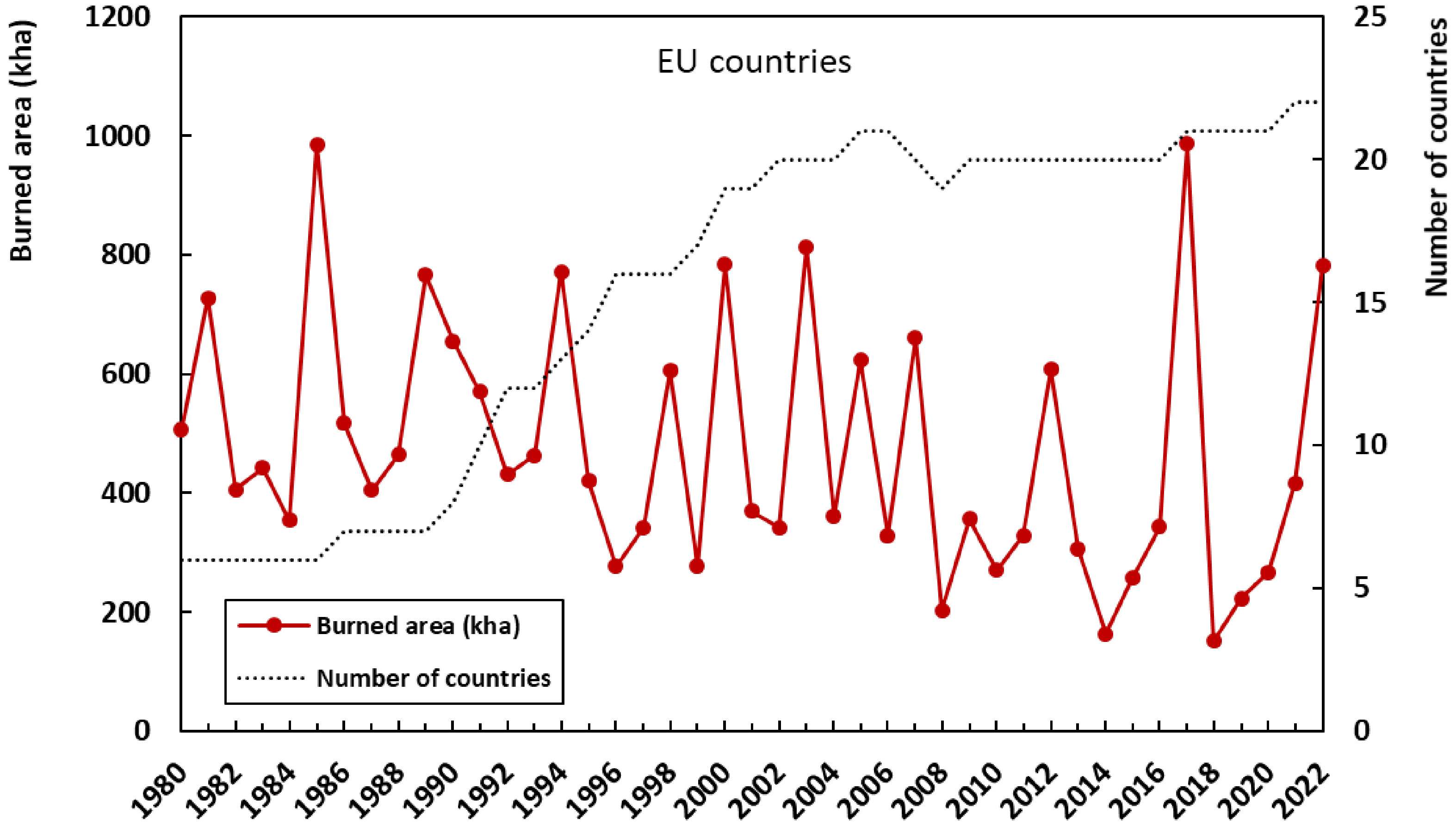
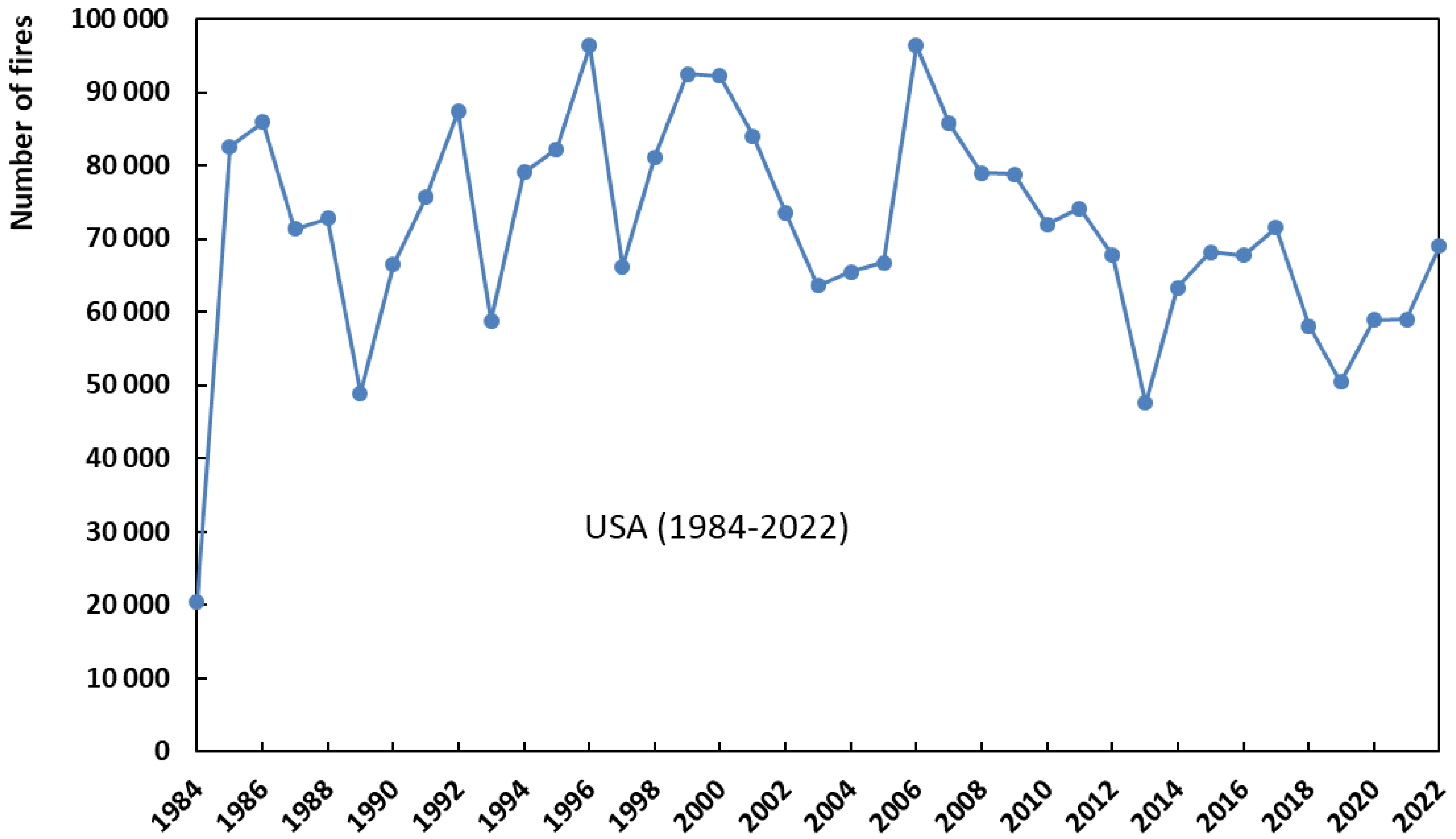
Burned area annually in Europe



Annual Number of Fires in the USA



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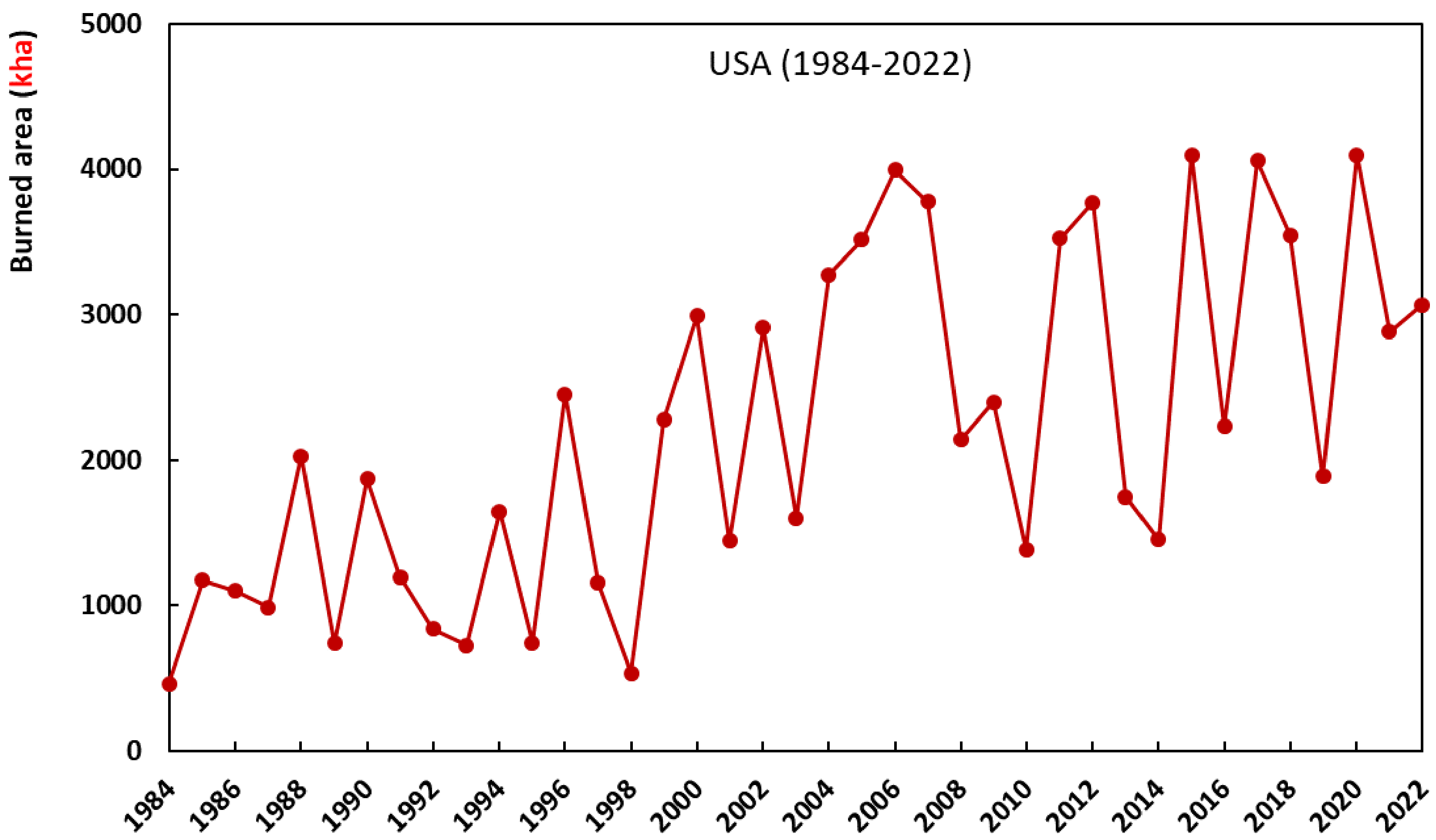
Burned area annually in the USA



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Team of the *Centro de Estudos sobre Incêndios Florestais* (CEIF)

Forest Fire Research Laboratory

Field experiments and observation of real fires

2. Integrated Forest Fire Risk Management

- In order to manage the risk of wildfires we need a sound assessment of all its components, a good methodology to reduce the risk and a path to adapt the system to changing conditions.
- Besides having an integrated strategy we also need a good structure of governance, to manage the risk operationally.

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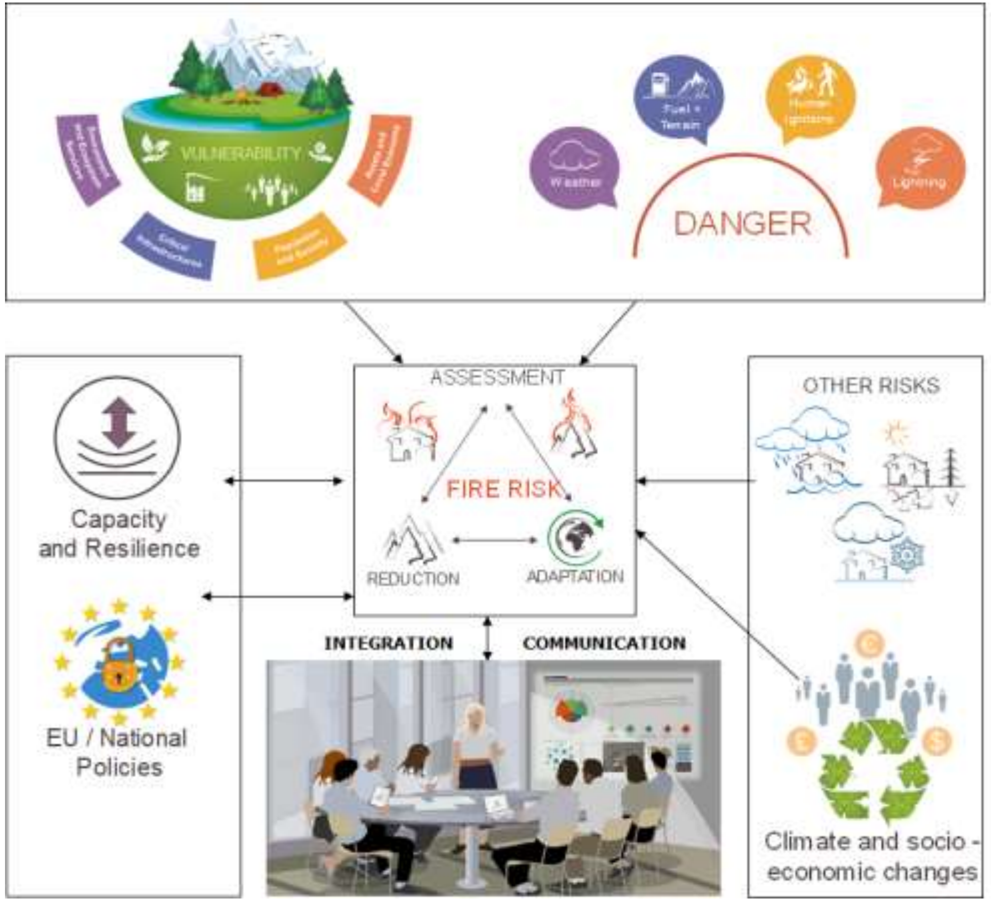
FirEUrisk Project

Developing a Holistic Risk-wise Strategy for Wildfire Management.

In FirEUrisk we study in particular the very large fires that endanger human life, considering all phases of the problem and different scales and levels of decision.



This project has been granted funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement no. 101003890

38 partners from 18 Countries

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- **Risk assessment**
  - Include various components of wildfire risk
  - Include social and ecological aspects
  - Focus on WUI areas
  - Involve local population in fire management aspects.

- **Risk reduction**
  - Test different risk reduction strategies
  - Reduce human made ignitions
  - Consider extreme wildfire events.

- **Risk adaptation**
  - Consider future climate and socio-economic scenarios.
  - Include social and ecological aspects
  - Consider new fire-prone regions
  - Improve resilience of WUI areas to extreme fire behaviour.

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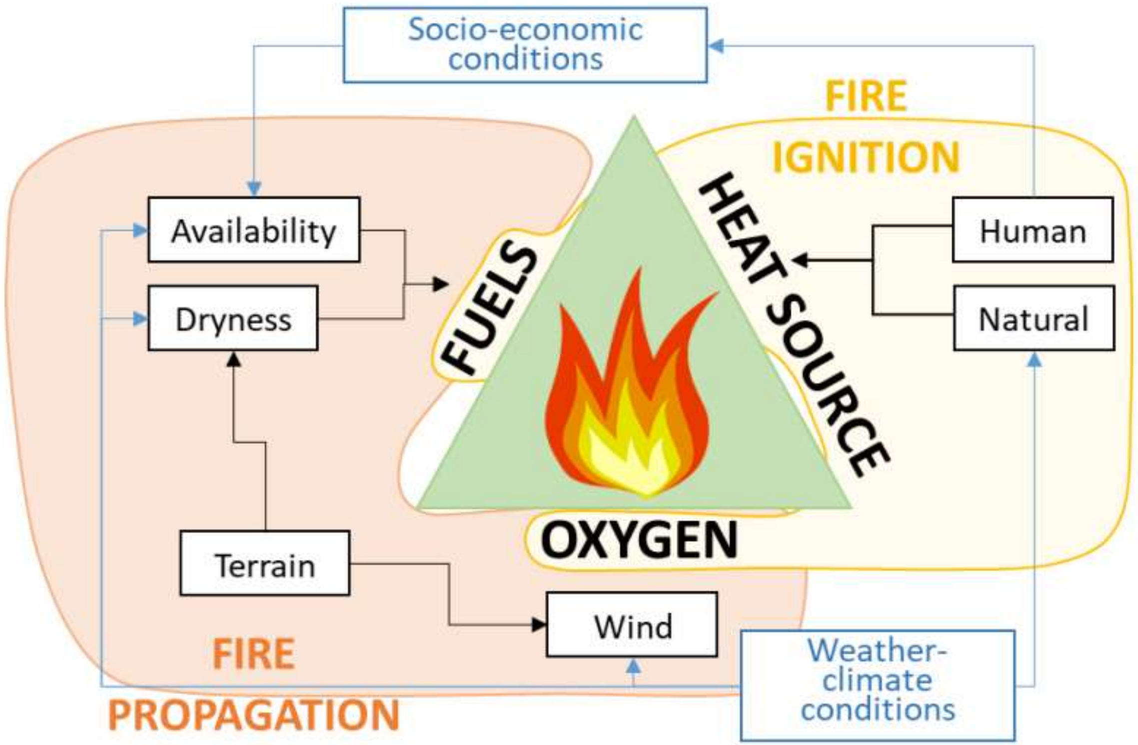
- In a recent paper we proposed an integrated approach to analyze the wildfire risk components.
- We consider the relevant parameters and variables at various time and space scales.
- We address all phases of fire management: before, during and after the fire.



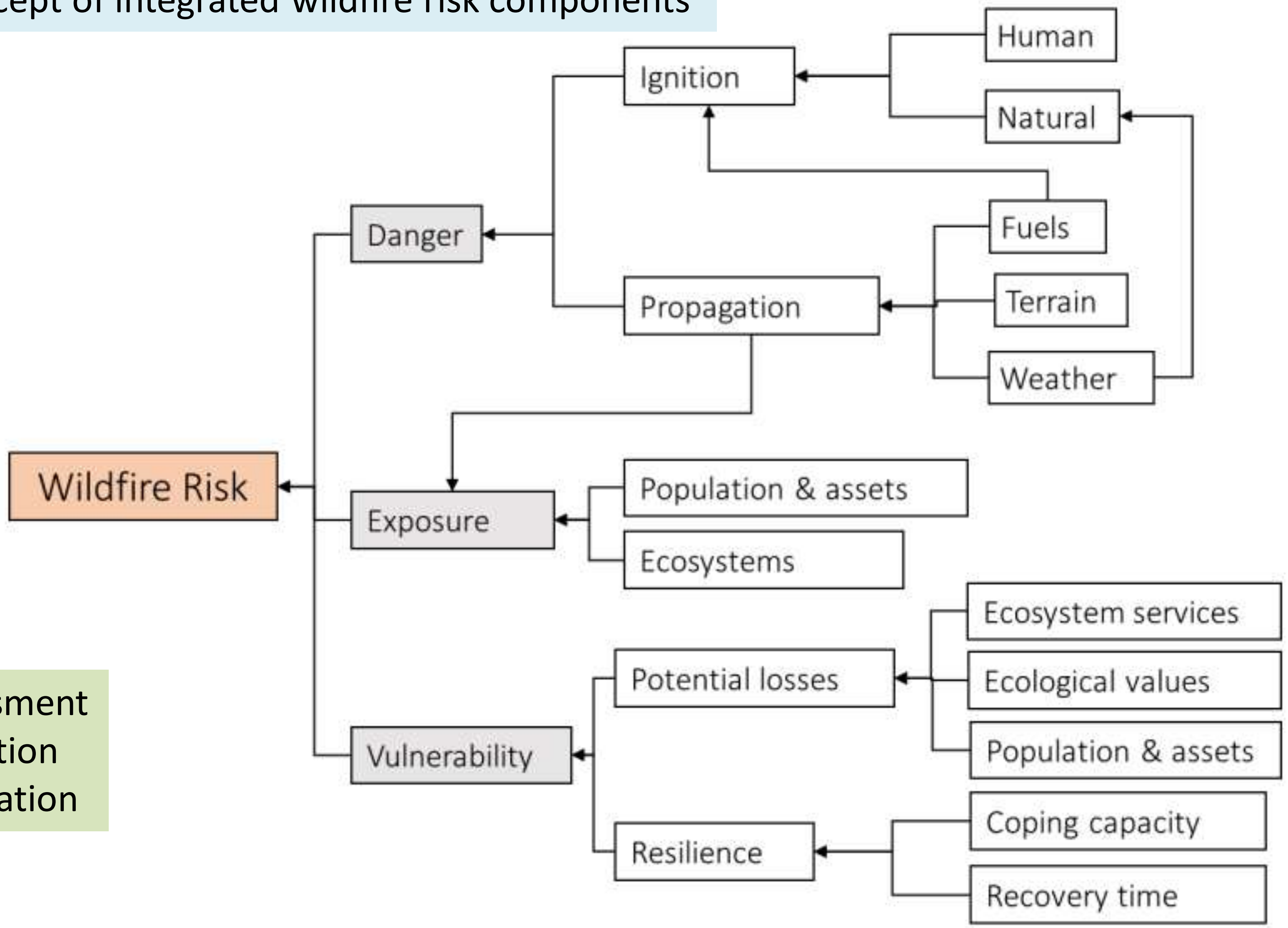
fire MDPI

Concept Paper

Towards an integrated approach to wildfire risk assessment: when, where, what and how may the landscapes burn.

Emilio Chuvieco, Marta Yebra, Simone Martino, Kirsten Thonicke, Marta Gómez-Giménez, Jesus San-Miguel, Duarte Oom, Ramona Velea, Florent Mouillot, Juan R. Molina, Ana I. Miranda, Diogo Lopes, Michele Salis, Marin Bugaric, Mikhail Sofiev, Evgeny Kadantsev, Ioannis Gitas, Dimitris Stavrakoudis, George Eftychidis, Avi Bar-Massada, Alex Neidermeier, Valerio Pampanoni, M. Lucrecia Pettinari, Fatima Arrogante, Clara Ochoa, Bruno Moreira and Domingos Viegas

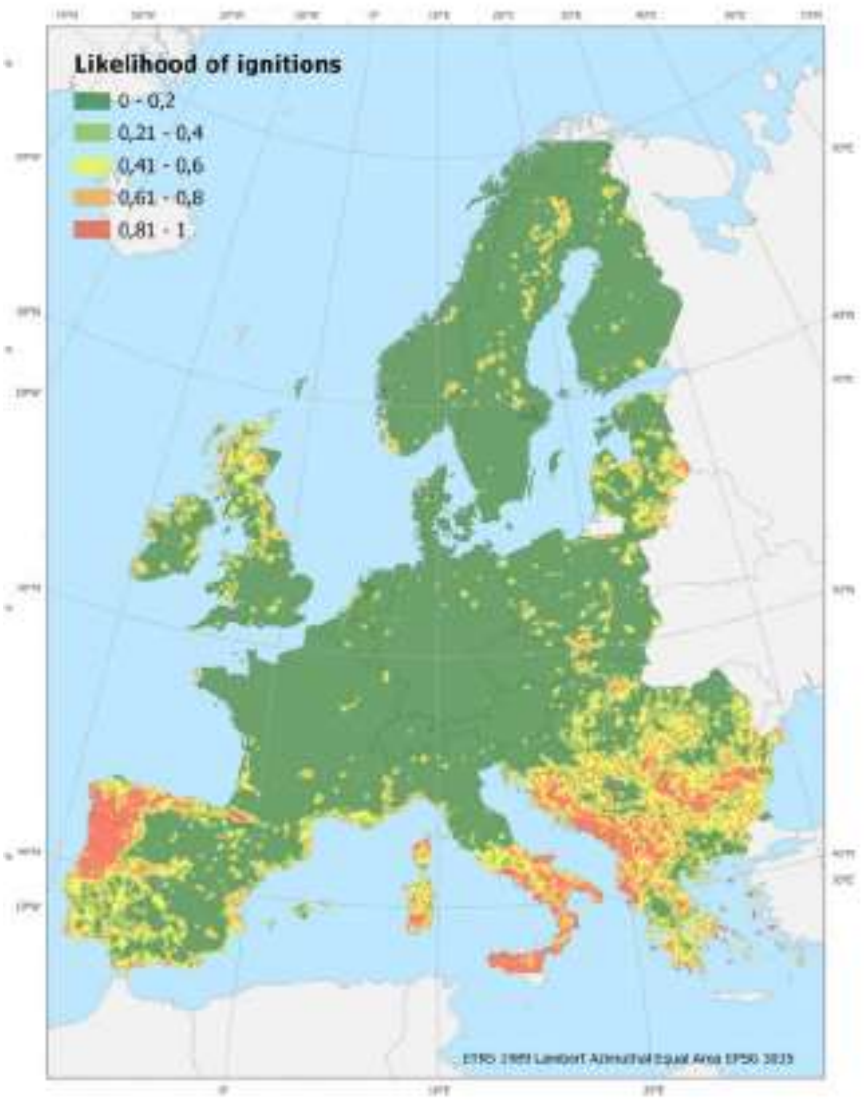
FirEUrisk Concept of integrated wildfire risk components



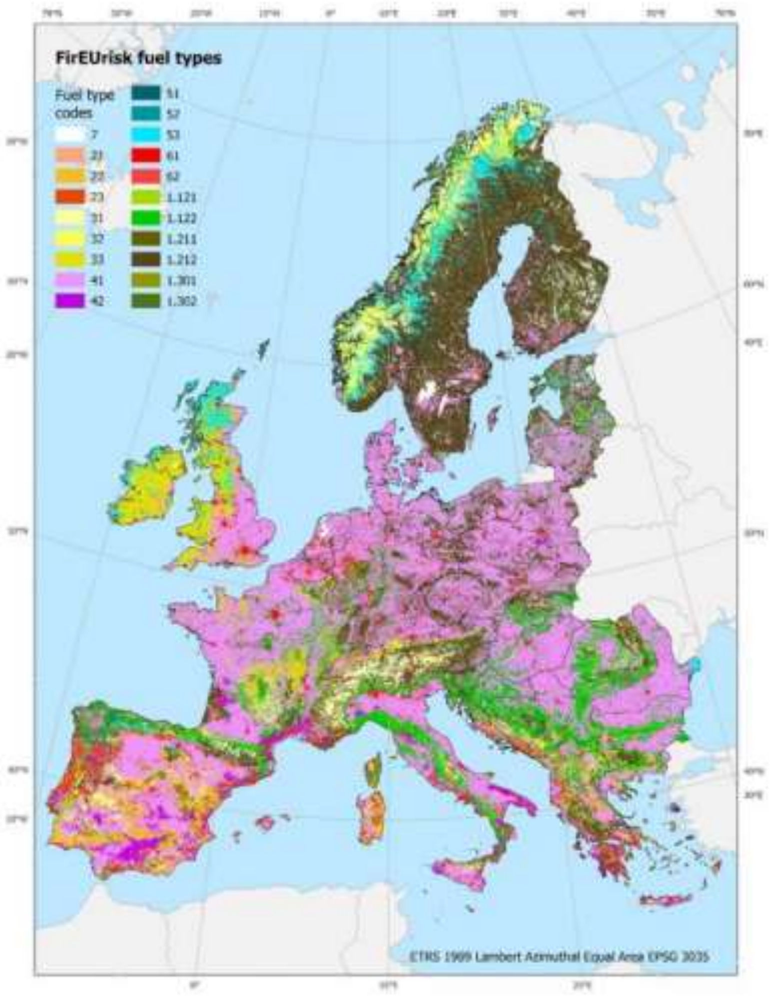
Risk assessment
Risk reduction
Risk adaptation

- Assessment of natural and human related ignitions.

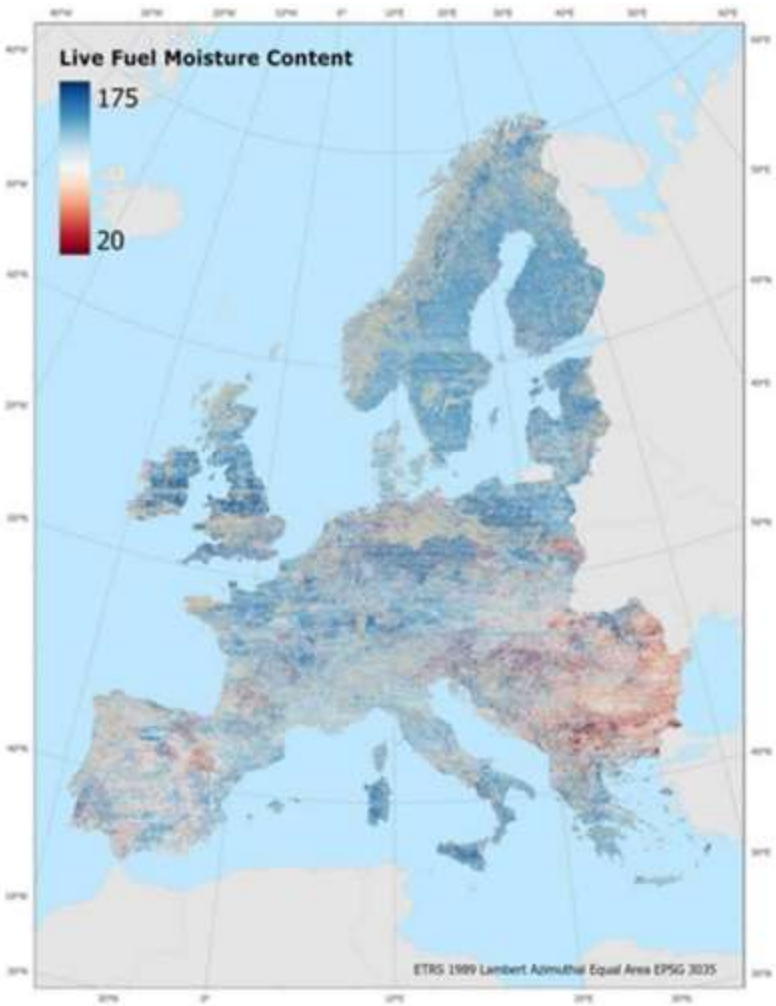
- Human ignitions were estimated on the basis of historical data and of models considering various factors like population density, distance to roads, type of vegetation cover, livestock density, etc.



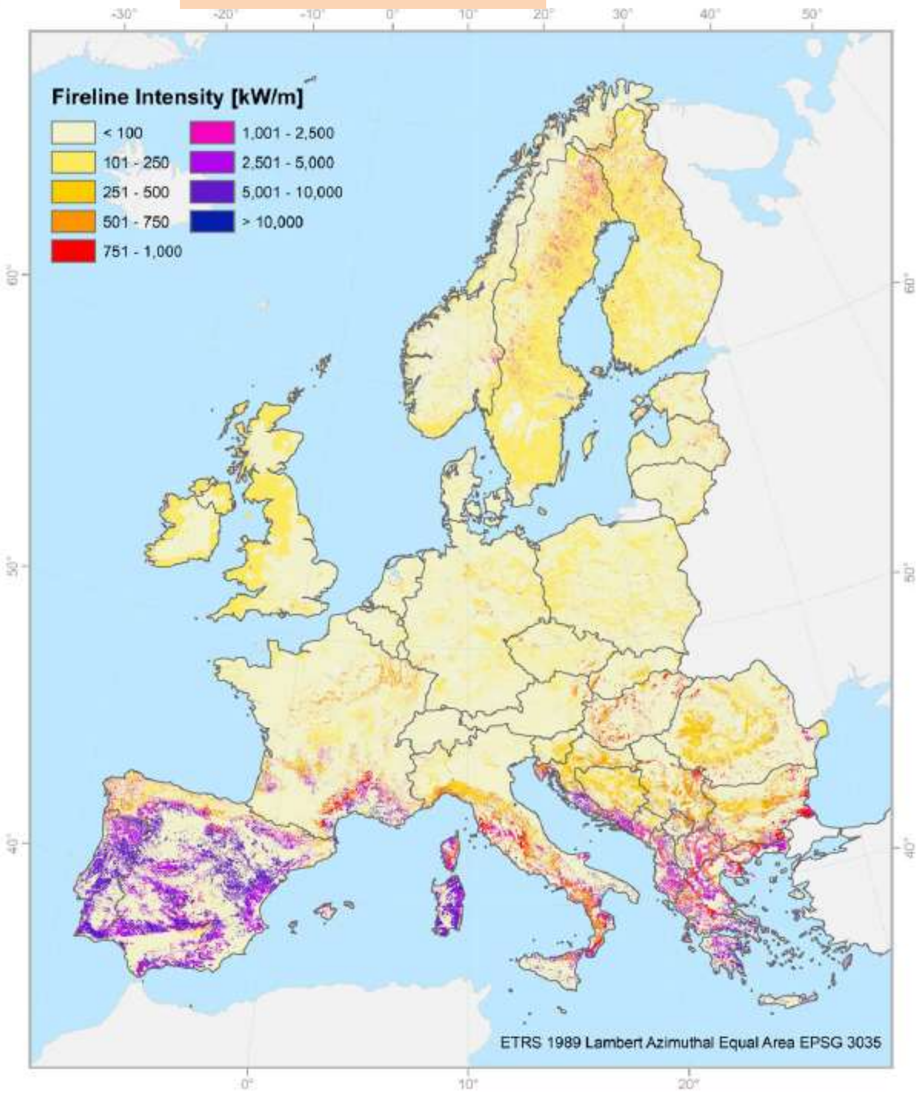
Fuel Type Cover



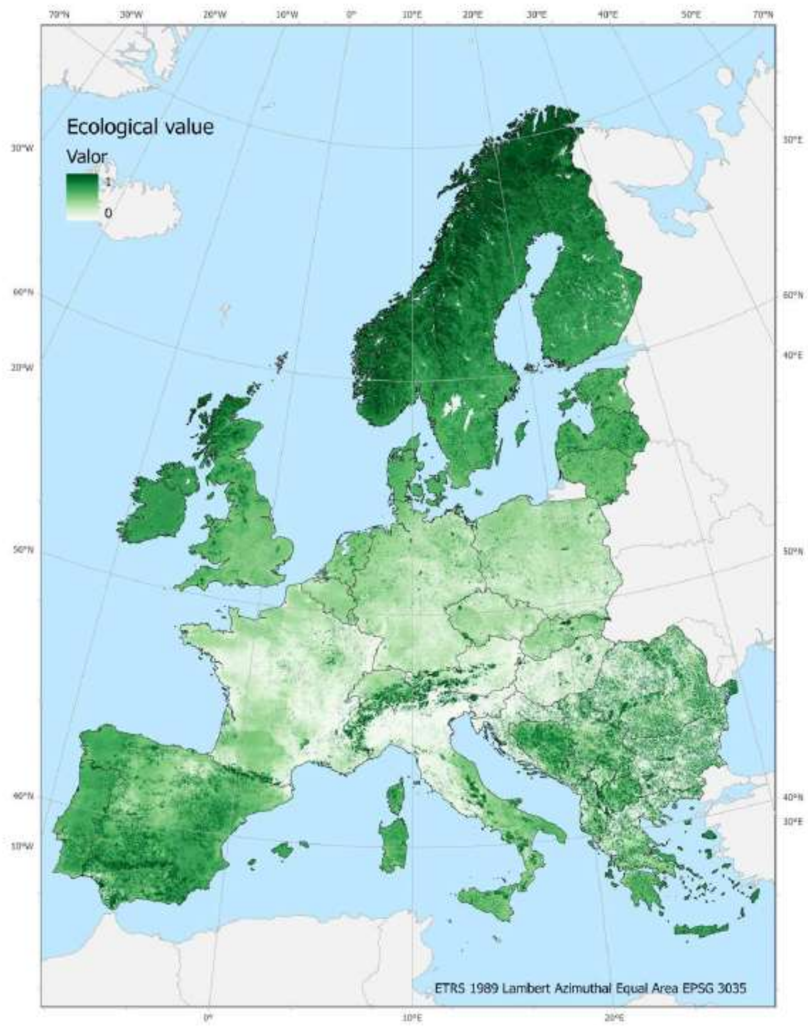
Live Fuel Moisture



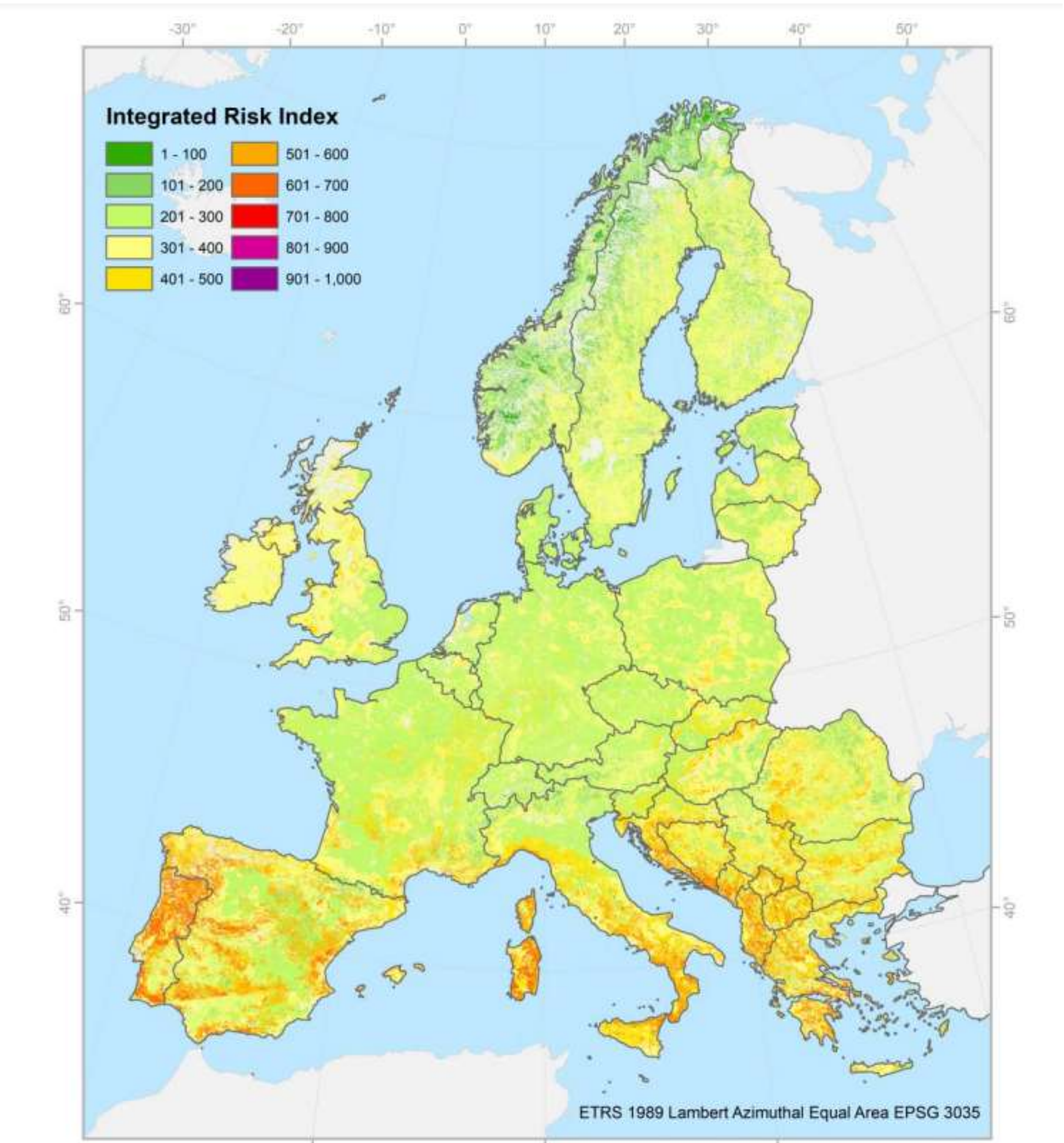
Fireline Intensity



Ecological Value



Integrated Risk Index
based of historical conditions leading to large wildfires in Europe



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3. Role of Science

- Within our research program, in the scope of various projects, namely FirEUrisk, we are developing several innovative solutions to support fire management in an integrated form.
- In the interest of time I will mention just two of them:
  - – Vegetation mapping and characterization.
  - – Fire behaviour modelling.

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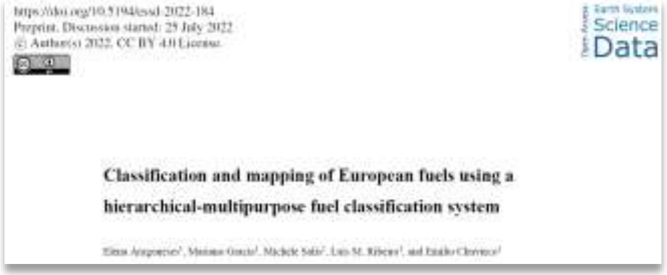
Development of a Fuel map for Europe

- One of the key elements to support FF management is the updated and detailed knowledge of the vegetation cover, which is a potential fuel.
- In FirEUrisk we proposed a methodology to classify the vegetation and to create a fuel map for the entire Europe.
- This map is based on satellite data and validated using several sources namely ground verification.
- This work had three objectives:
  - Develop a fuel classification system
  - Propose an European Fuel Map (1 km^2)
  - Develop fuel model parameterization


https://doi.org/10.5194/essd-2022-184
Preprint. Discussion started: 25 July 2022
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Earth System Science Data

Classification and mapping of European fuels using a hierarchical-multipurpose fuel classification system

- FirEUrisk Fuel Categories Classification:
  1. Forest
  2. Shrubland
  3. Grassland
  4. Cropland
  5. Wet and peat/semi-peat land
  6. Urban
  7. Non fuel
- We identified 20 first-level fuel types and around 80 different fuel sub-types.

First-level Fuel types

FirEUrisk fuel type	
Code	**Description**
1111	Open broadleaf evergreen forest
1112	Closed broadleaf evergreen forest
1121	Open broadleaf deciduous forest
1122	Closed broadleaf deciduous forest
1211	Open needleleaf evergreen forest
1212	Closed needleleaf evergreen forest
1221	Open needleleaf deciduous forest
1222	Closed needleleaf deciduous forest
1301	Open mixed forest
1302	Closed mixed forest
21	Low shrubland [0-0.5 m)
22	Medium shrubland [0.5-1.5 m)

FirEUrisk fuel type	
Code	**Description**
23	High shrubland [≥ 1.5 m)
31	Low grassland [0-0.3 m)
32	Medium grassland [0.3-0.7 m)
33	High grassland [≥ 0.7 m)
41	Herbaceous cropland
42	Woody cropland
51	Tree wet and peat/semi-peat land
52	Shrubland wet and peat/semi-peat land
53	Grassland wet and peat/semi-peat land
61	Urban continuous fabric
62	Urban discontinuous fabric
7	Nonfuel

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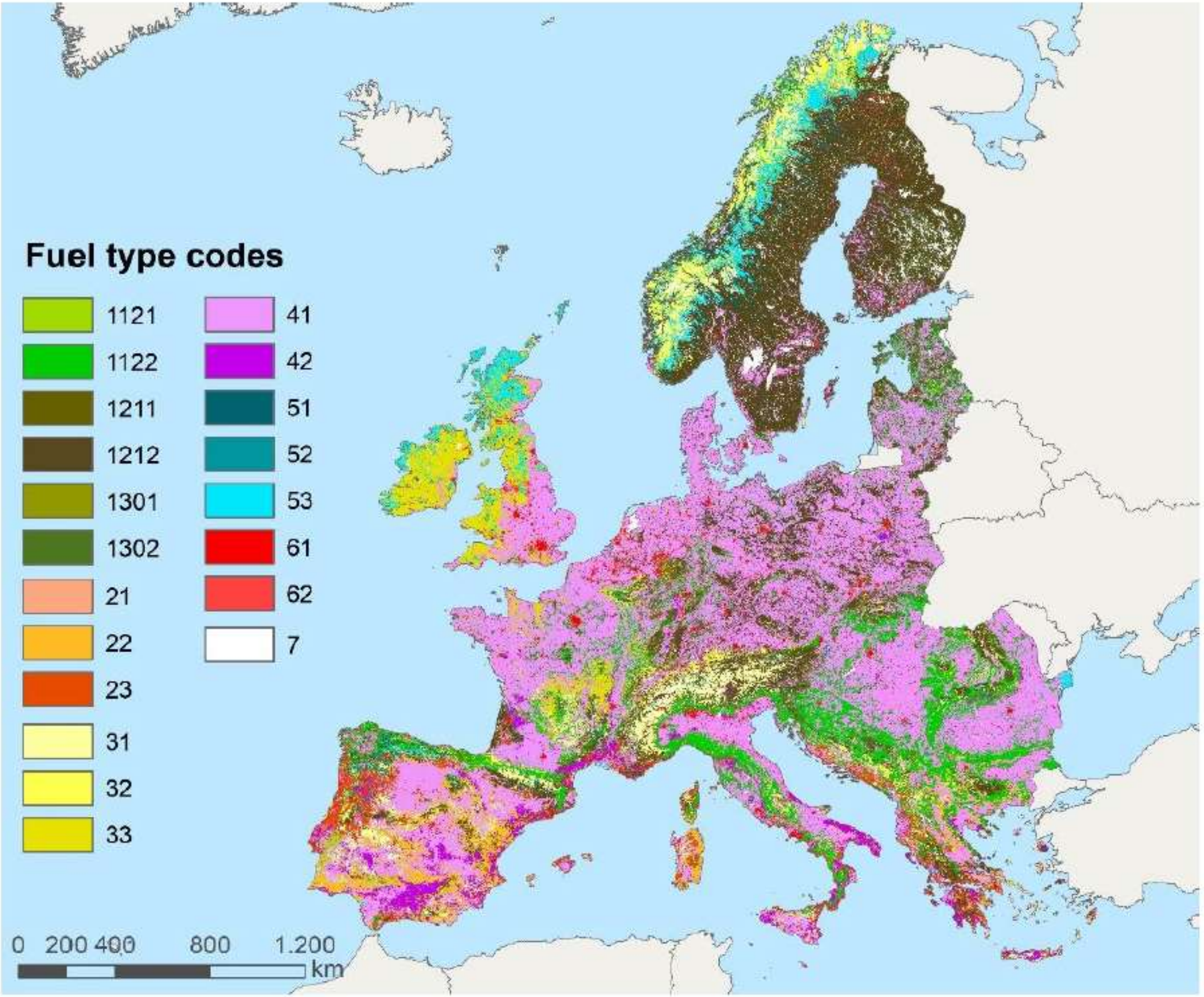

FirEUrisk European Fuel Map at 1km^2 resolution

From Fuel Types to Fuel Models

FirEUrisk fuel type	Crosswalk	
	A*	H*
1111	SH7	SH8
1112	TU1	TU2
1121	SH5	SH9
1122	TU5	TU3
1211	SH7	SH8
1212	TU1	TU2
1221	SH5	SH9
1222	TU5	TL3
1301	SH7	SH8
1302	TU5	TL3
21	SH2	SH3
22	SH7	SH8

FirEUrisk fuel type	Crosswalk	
	A*	H*
23	SH5	SH9
31	GR2	GR6
32	GR4	GR8
33	GR7	GR9
41	GR4	GR6
42	GR2	GR6
51	SH7	SH8
52	SH5	SH9
53	GR7	GR9
61	NB	NB
62	SH2	SH3
7	NB	NB

Fuel Types associated to Fuel Models of the Scott and Burgan FB Fuel Models (Scott and Burgan, 2005).

A* Arid/semi arid

H* Sub-humid/humid

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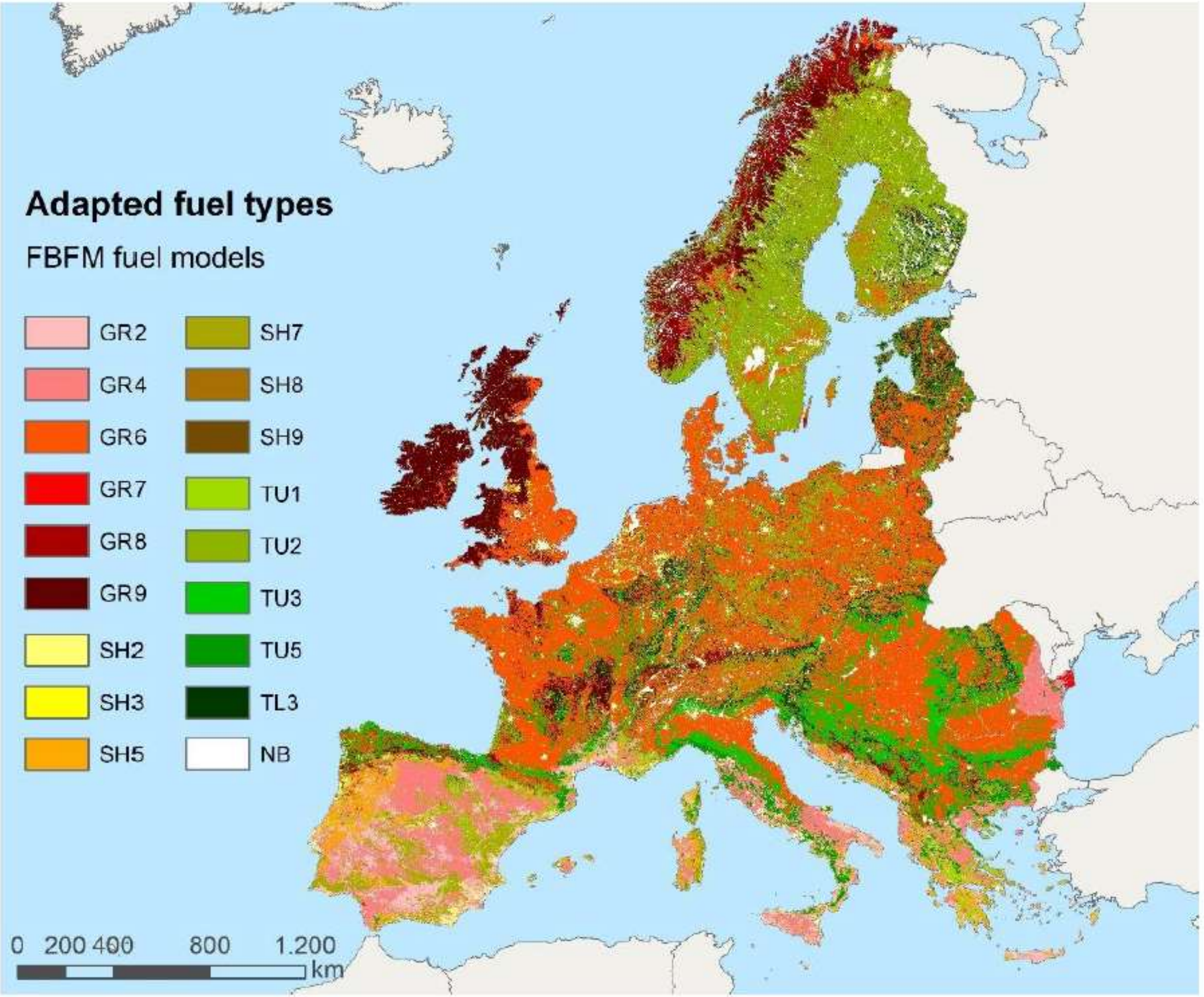
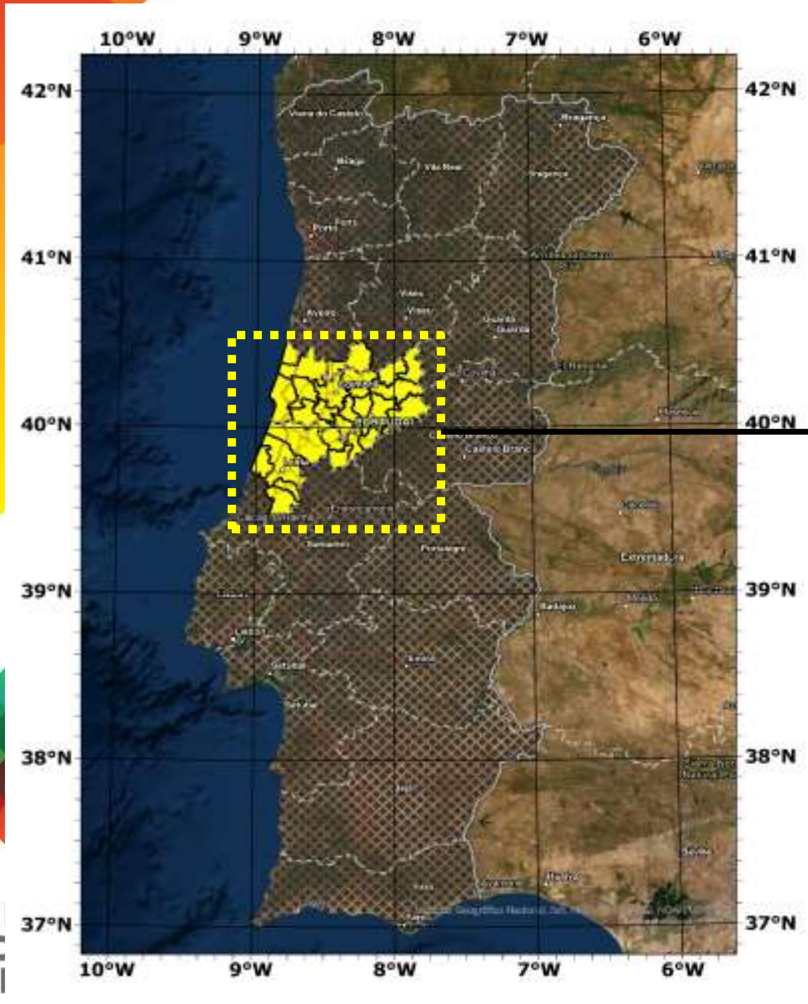
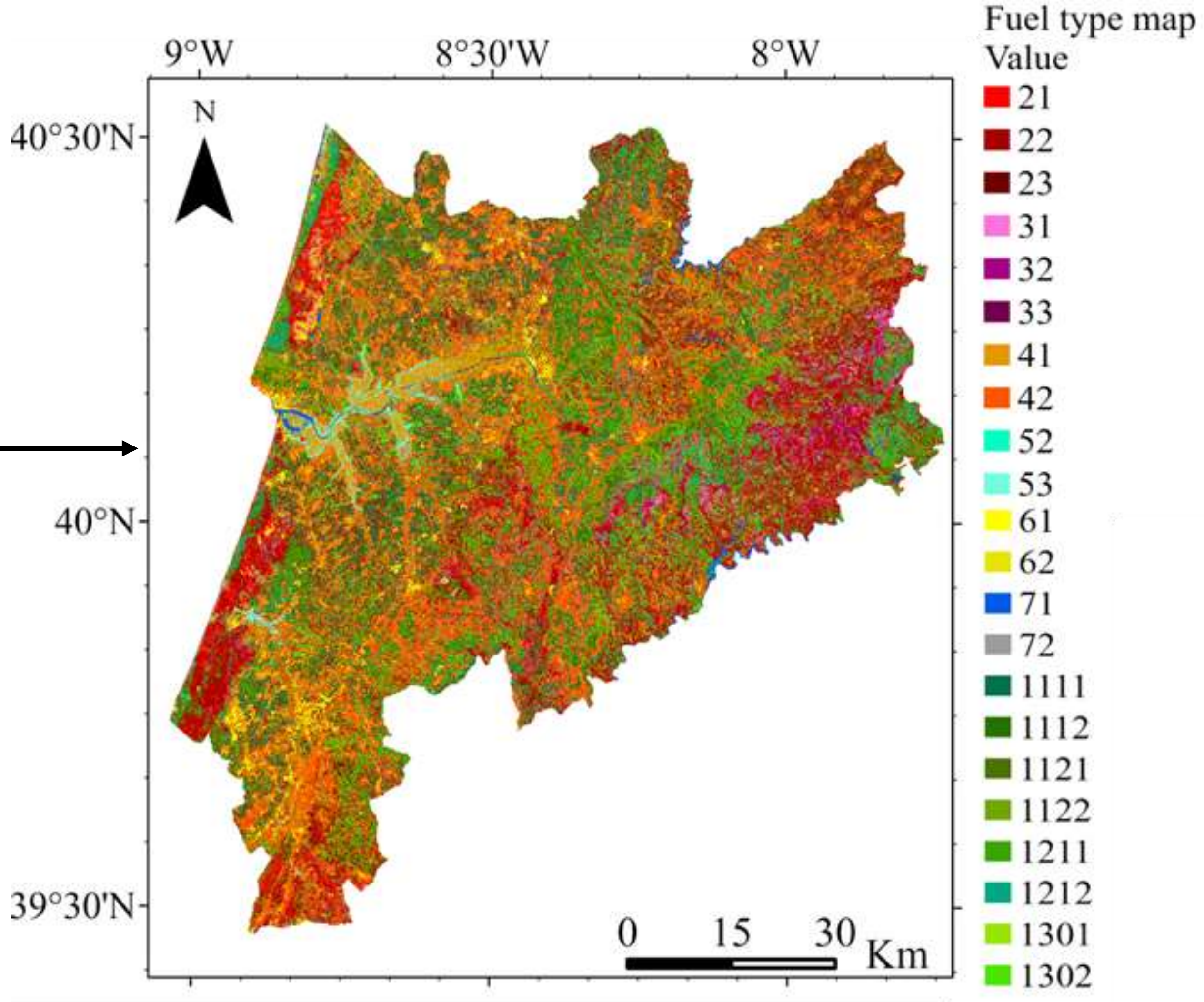


European Fuel Models at $1km^2$ resolution

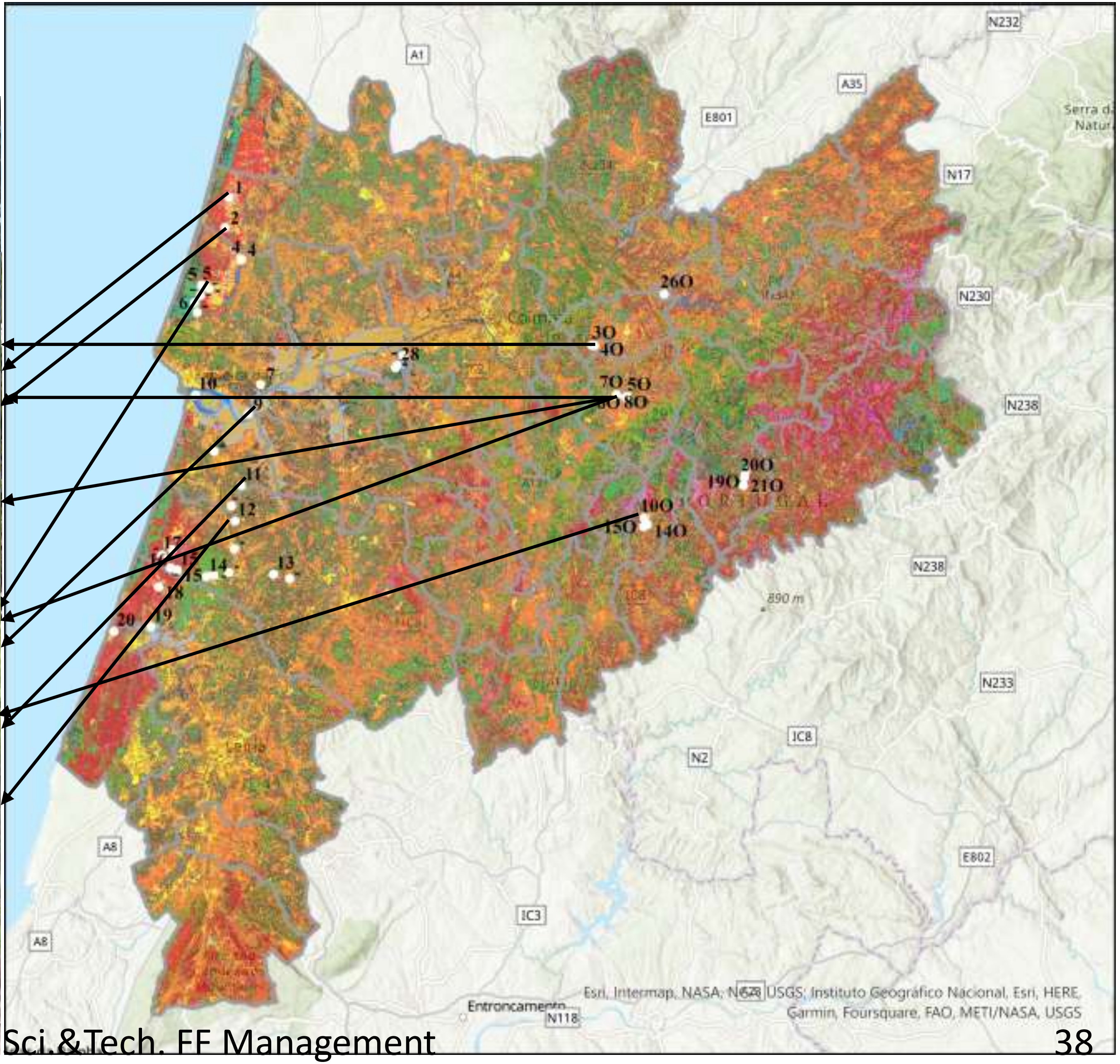
Study Area in Central Portugal



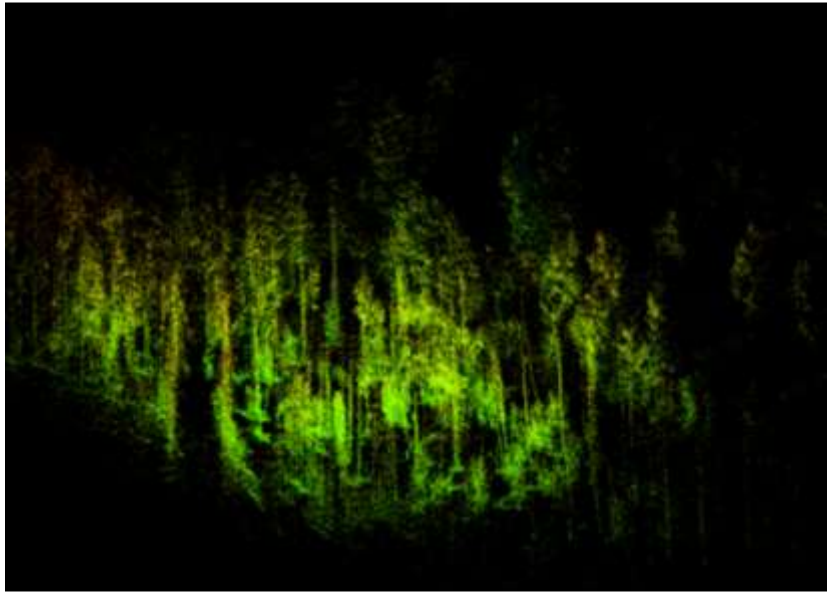


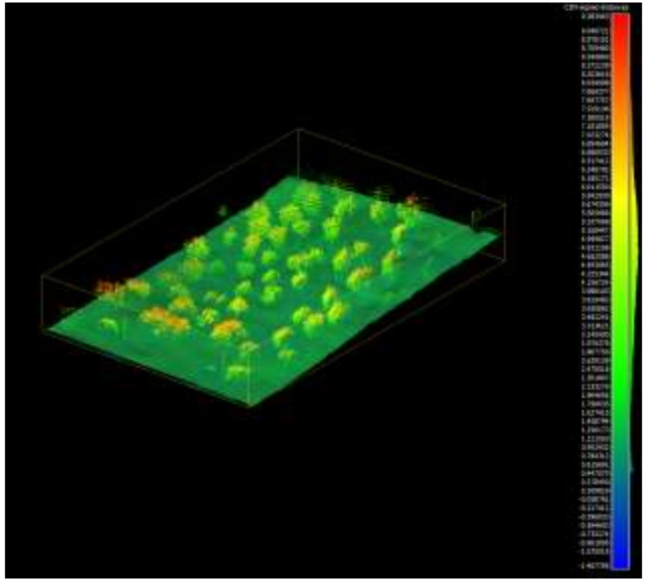
FirEUrisk Pilot site 3

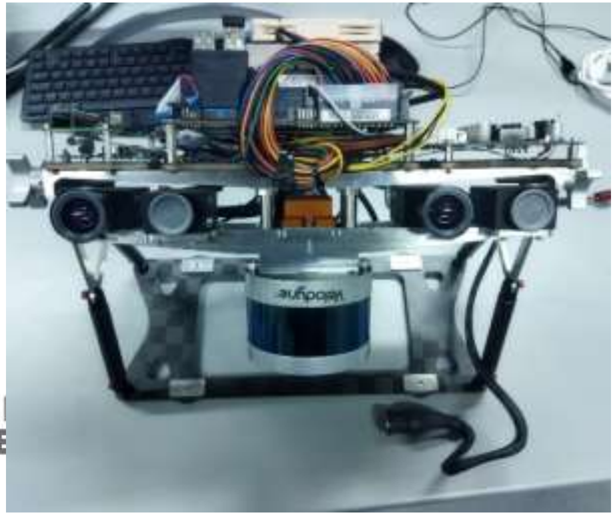
Field Survey

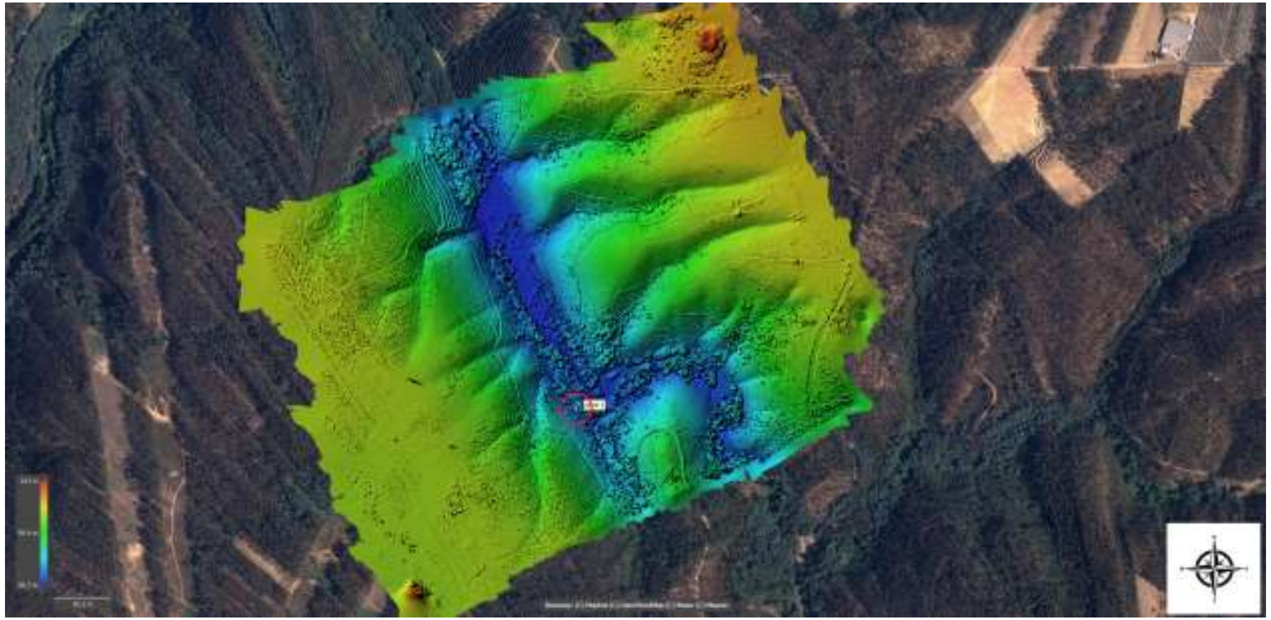


Use of drones flying multispectral sensors to validate the satellite data at regional scale









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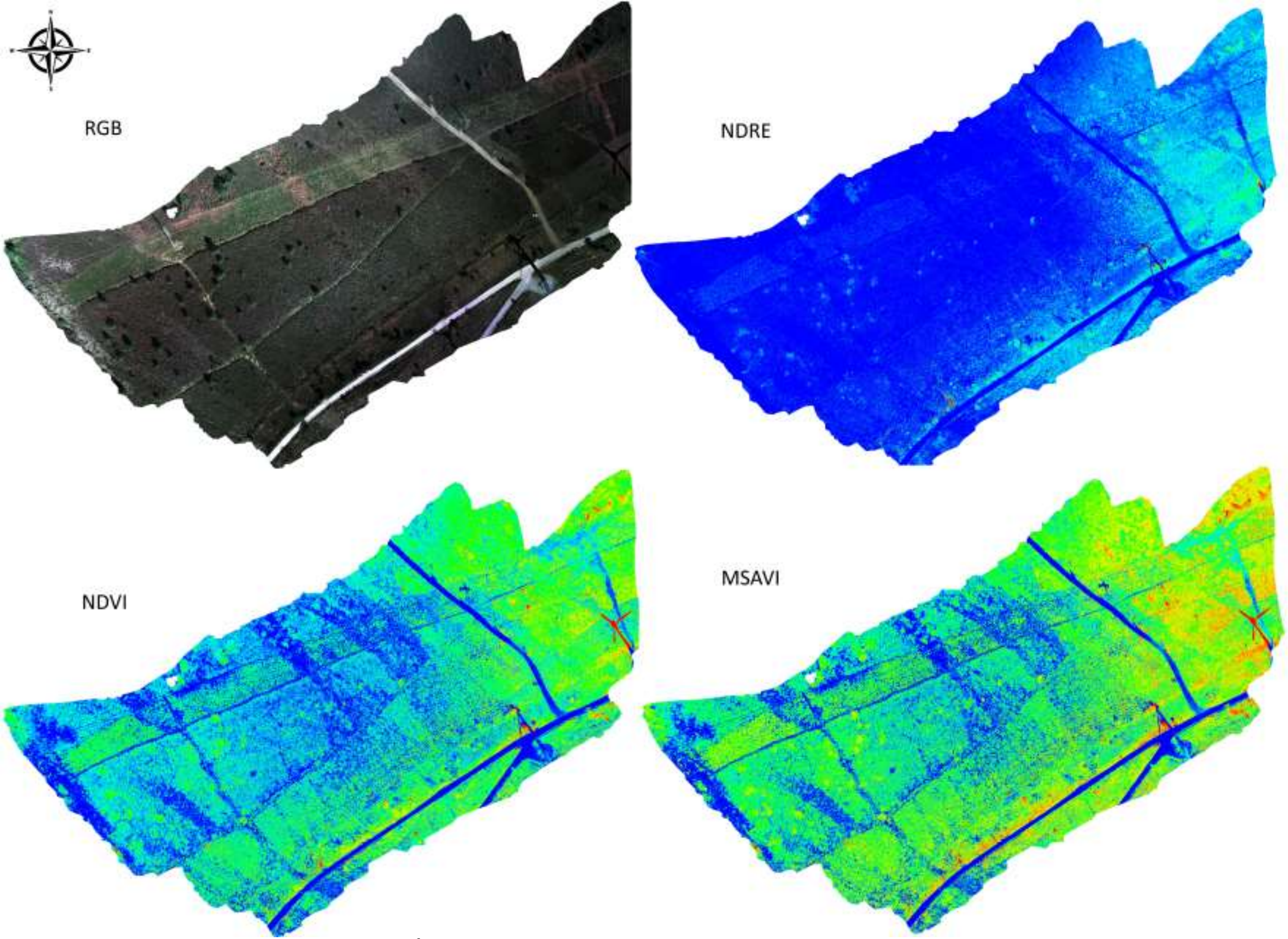

Surface fire behaviour

- The interaction between the convective flows induced by the fire and the surrounding ambient modify the spread conditions of the fire, even if the remaining conditions remain constant.
- In Viegas, 2004, it was shown that in the general case the ROS depends explicitly on time.
- In the analysis of fire behaviour it is usual to consider the so called "Triangle of Fire Factors"; we propose the alternative concept of "Square of Fire Factors".

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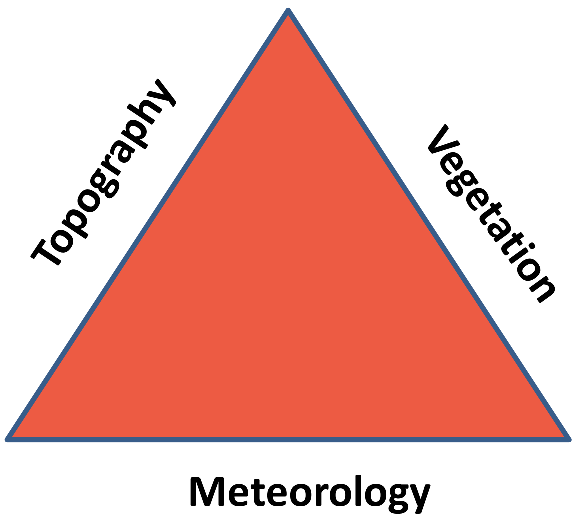
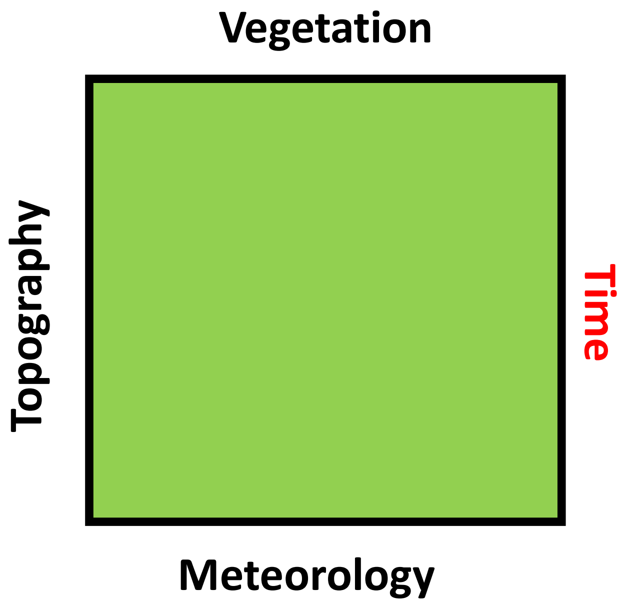
- "Square" vs. "Triangle" of Fire Factors

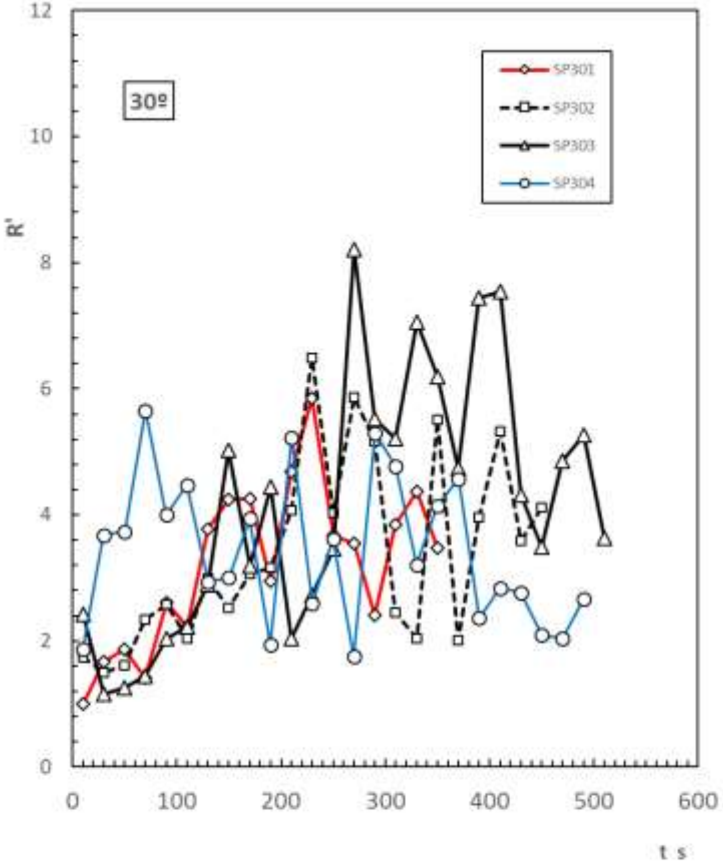


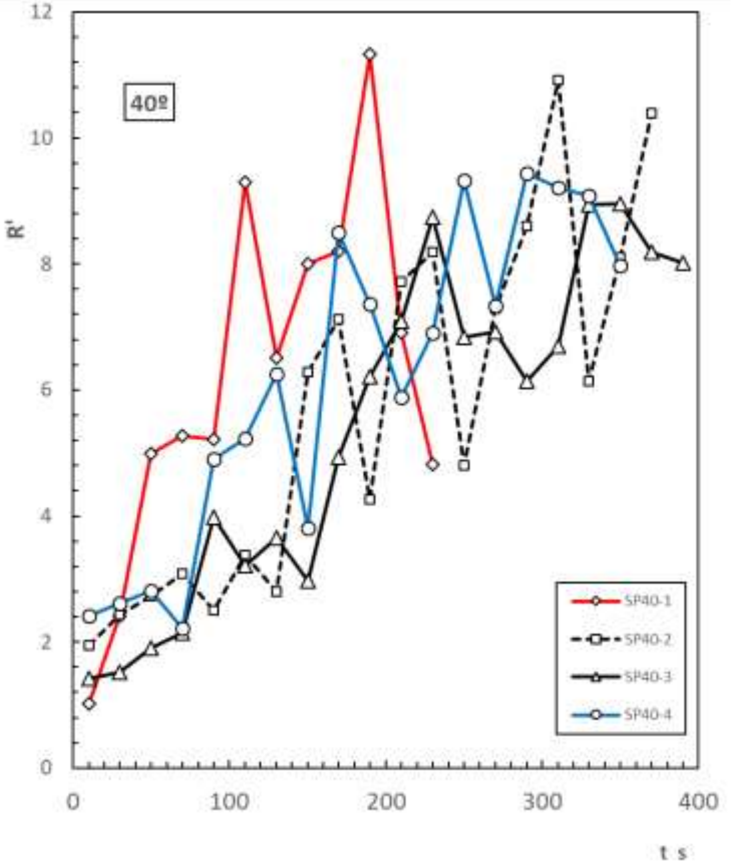


Spread of a point ignition fire on a slope

$$R' = \frac{R}{R_o}$$

R_o is the basic rate of spread in no slope and no wind conditions





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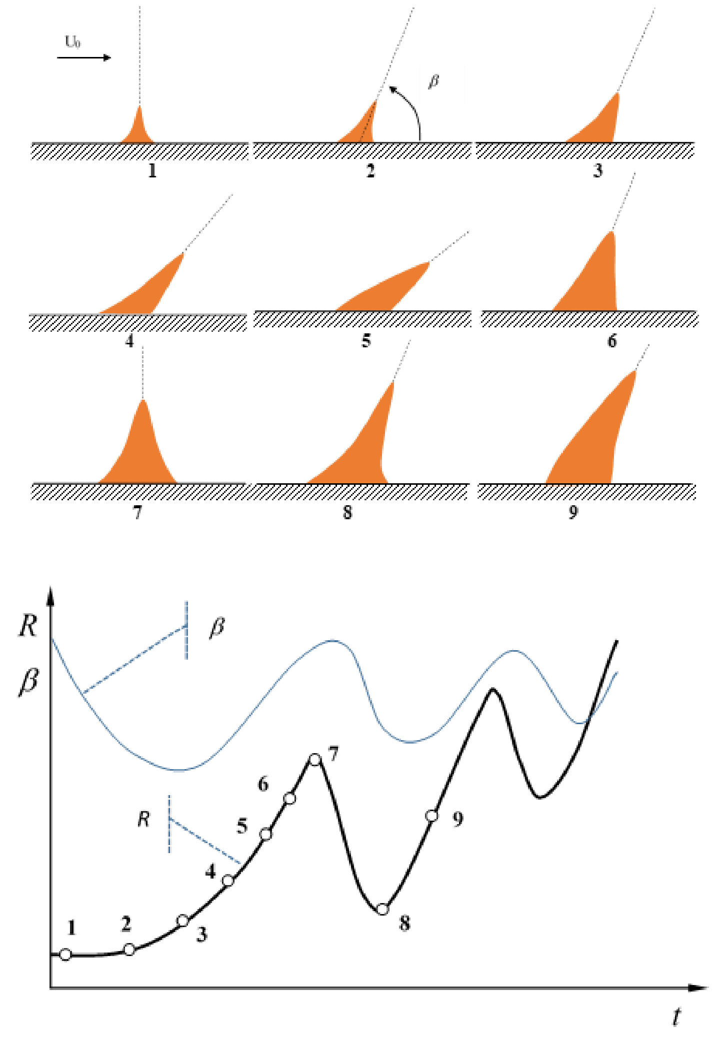
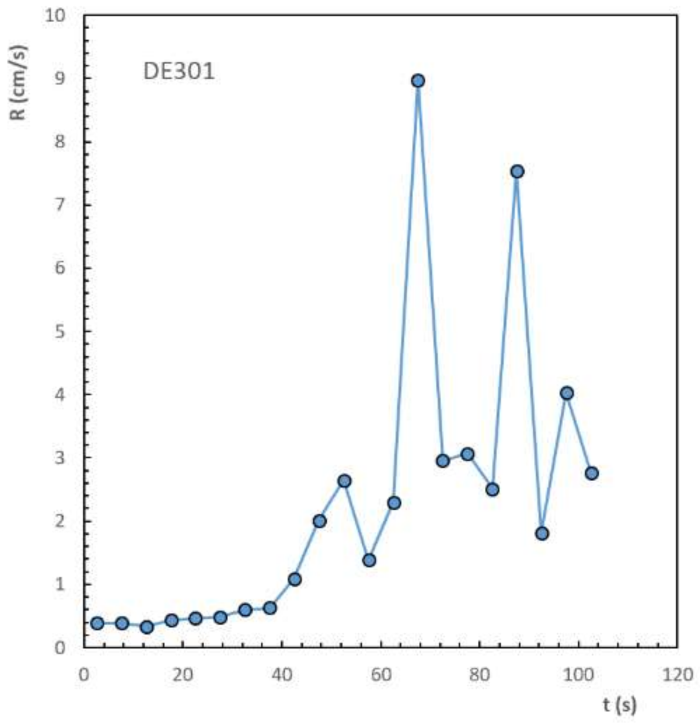
Intermittent or oscillatory fire behaviour

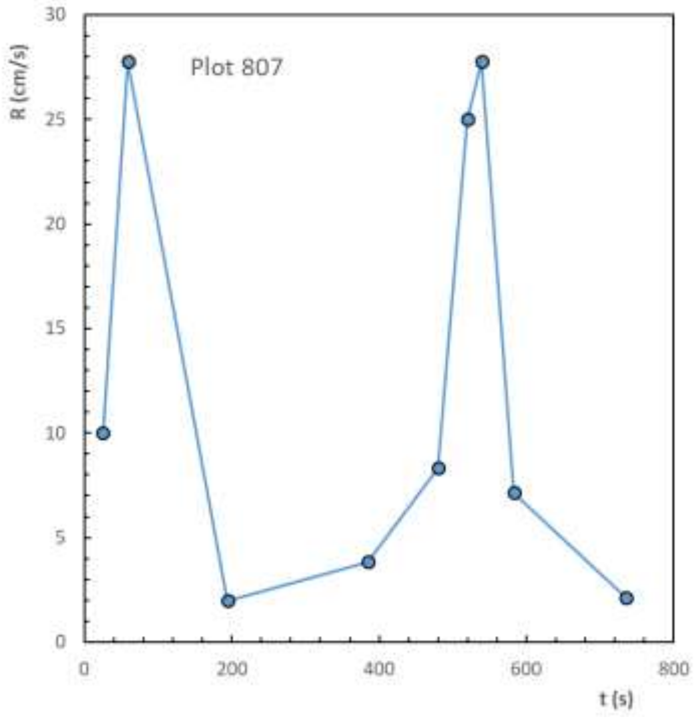
- The behaviour of a fire is oscillatory and intermittent: its ROS may increase, but the convective flow induced by the fire will counteract the acceleration tendency and decrease the ROS value.

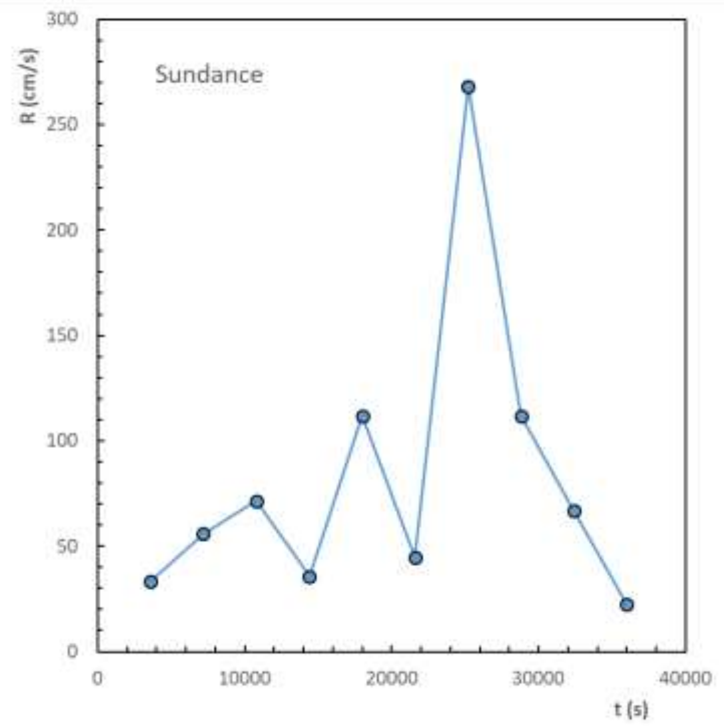
- If the boundary conditions remain the same the fire will undergo another cycle of ROS increase and decrease.



Viegas DX, et al., 2021. On the non-monotonic Behavior of Fire Spread, Int. J. Wildland Fire. https://doi.org/10.1071/WF21016.







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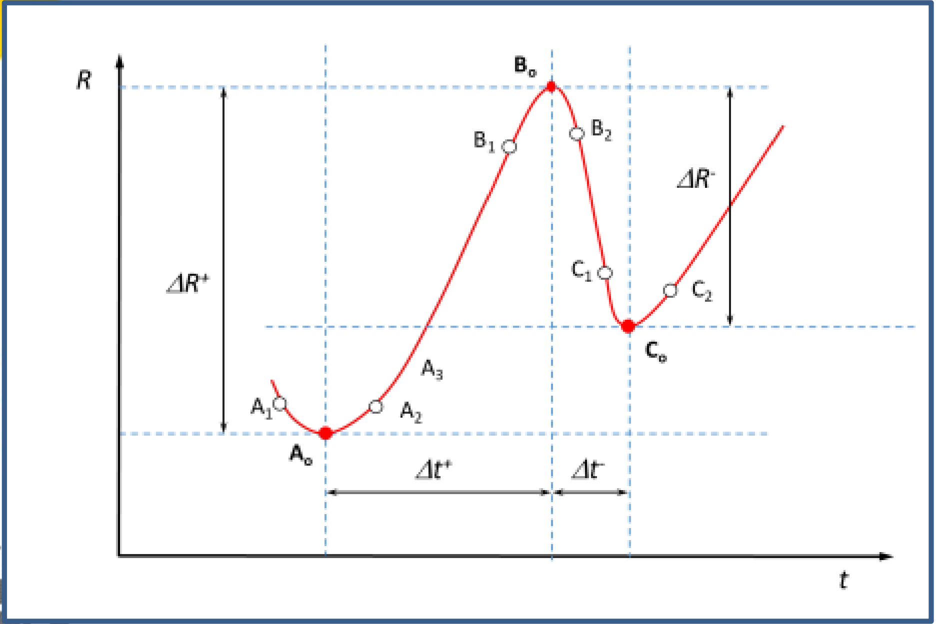
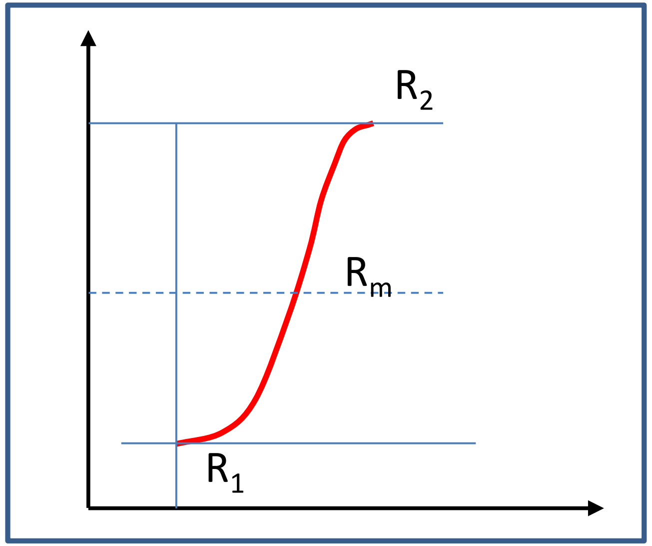
Laboratory Test	Field experiment	Sundance Fire
2 minutes	12 minutes	10 hours

R(t) during fire evolution
in two semi-periods





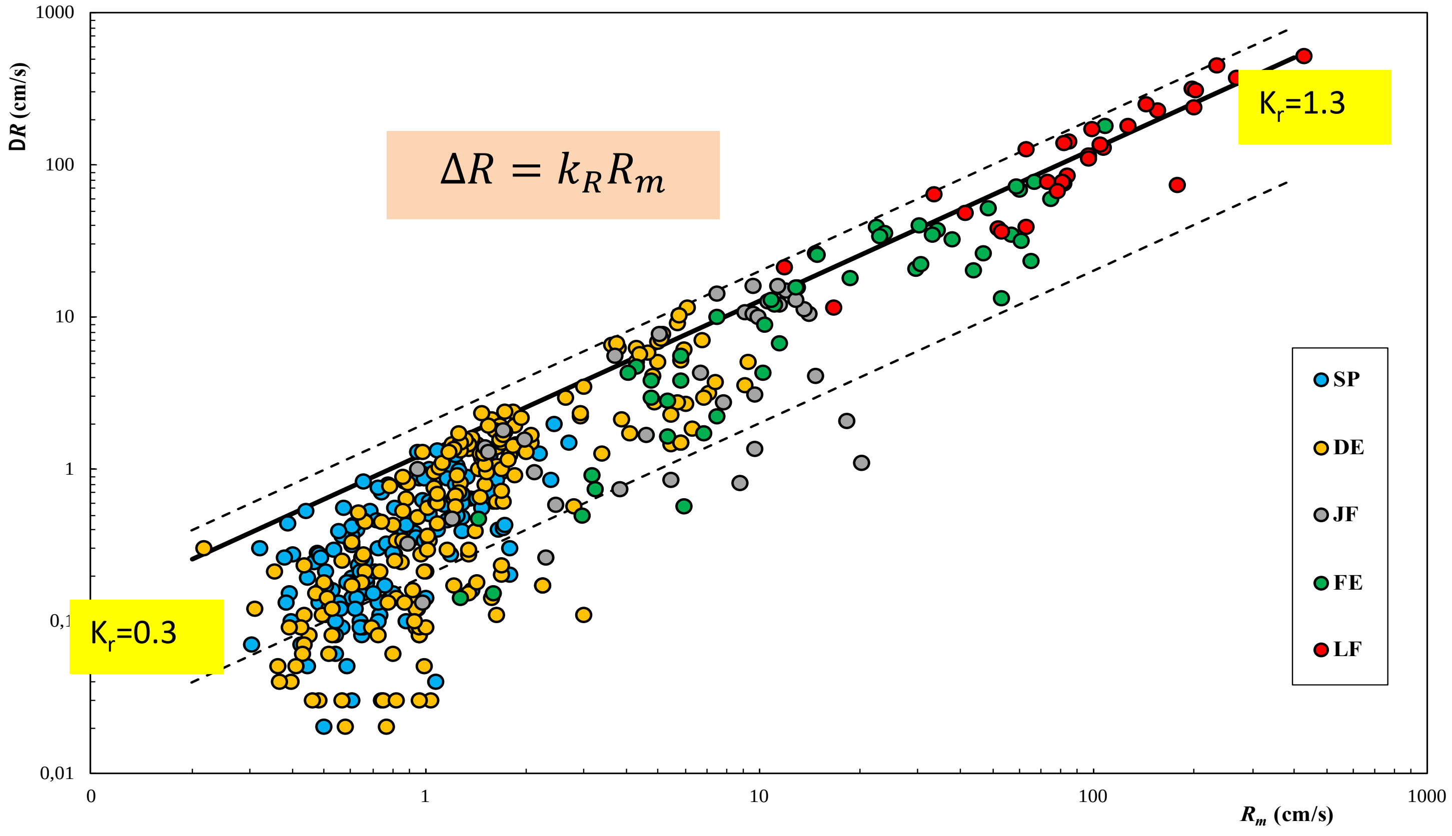
Average value of the ROS R_m

$$R_m = \frac{R_1 + R_2}{2}$$

Amplitude of the fluctuation of the ROS

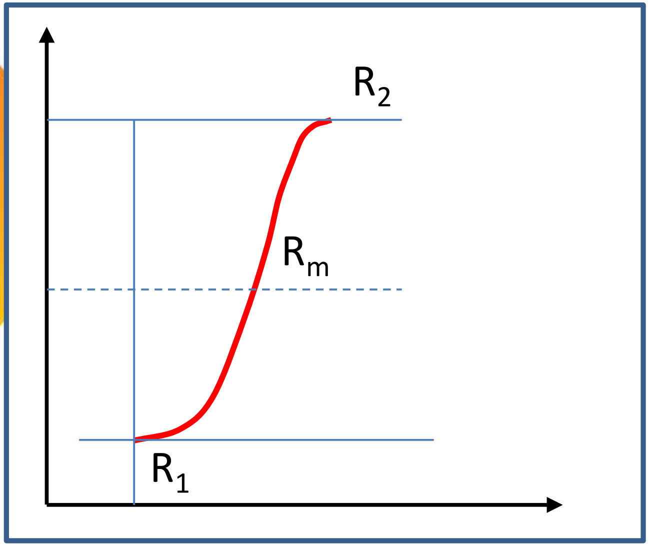
$$\Delta R = R_2 - R_1$$

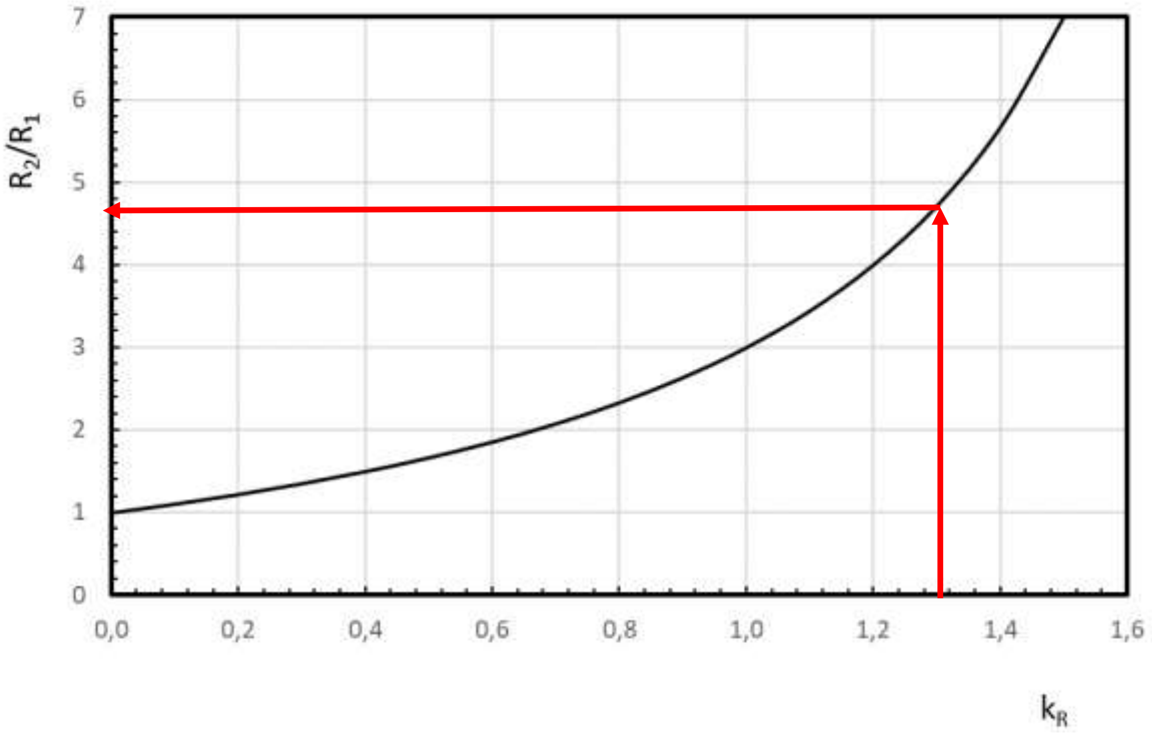
Amplitude of fluctuations



Laboratory Field Real Fires

Universidade de Coimbra





$$\Delta R = k_R R_m = k_R \frac{R_1 + R_2}{2}$$

$$\frac{R_2}{R_1} = \frac{2 + k_R}{2 - k_R}$$

$$k_R = 1.3 \rightarrow \frac{R_2}{R_1} \approx 5$$

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Extreme Fire Behaviour

- There are various modes of extreme fire behaviour, that can surprise and endanger people facing the fire.

- Two of them are of particular concern as they are driven by the dynamic interaction between the fire and its surrounding.

- These are the "Eruptive fires" that occur in canyons and in steep slopes, and the "Junction fires" that occur when two fires merge.

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Eruptive fire in a canyon

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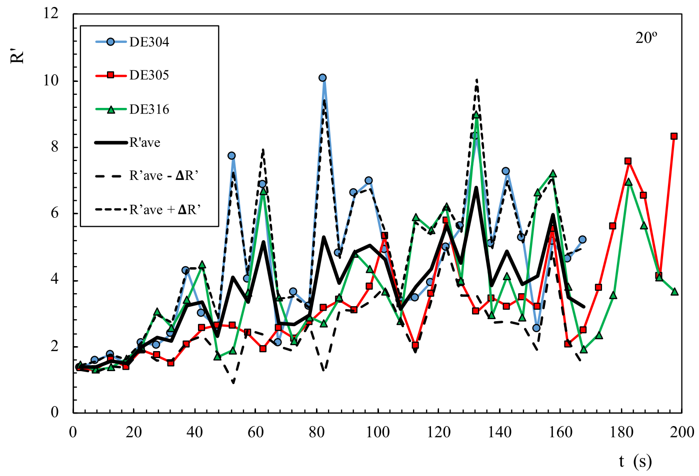
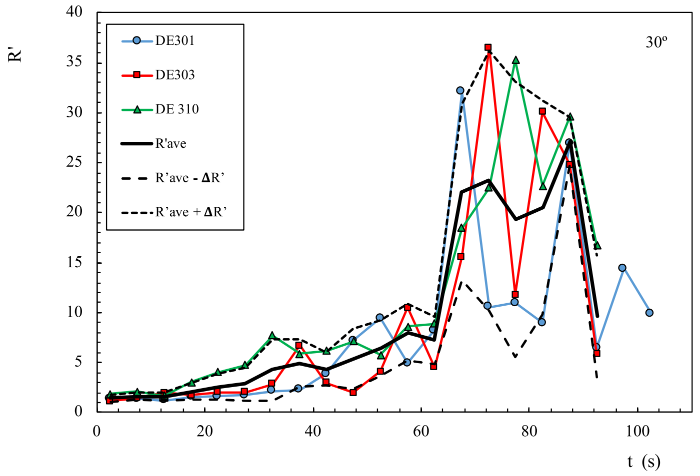
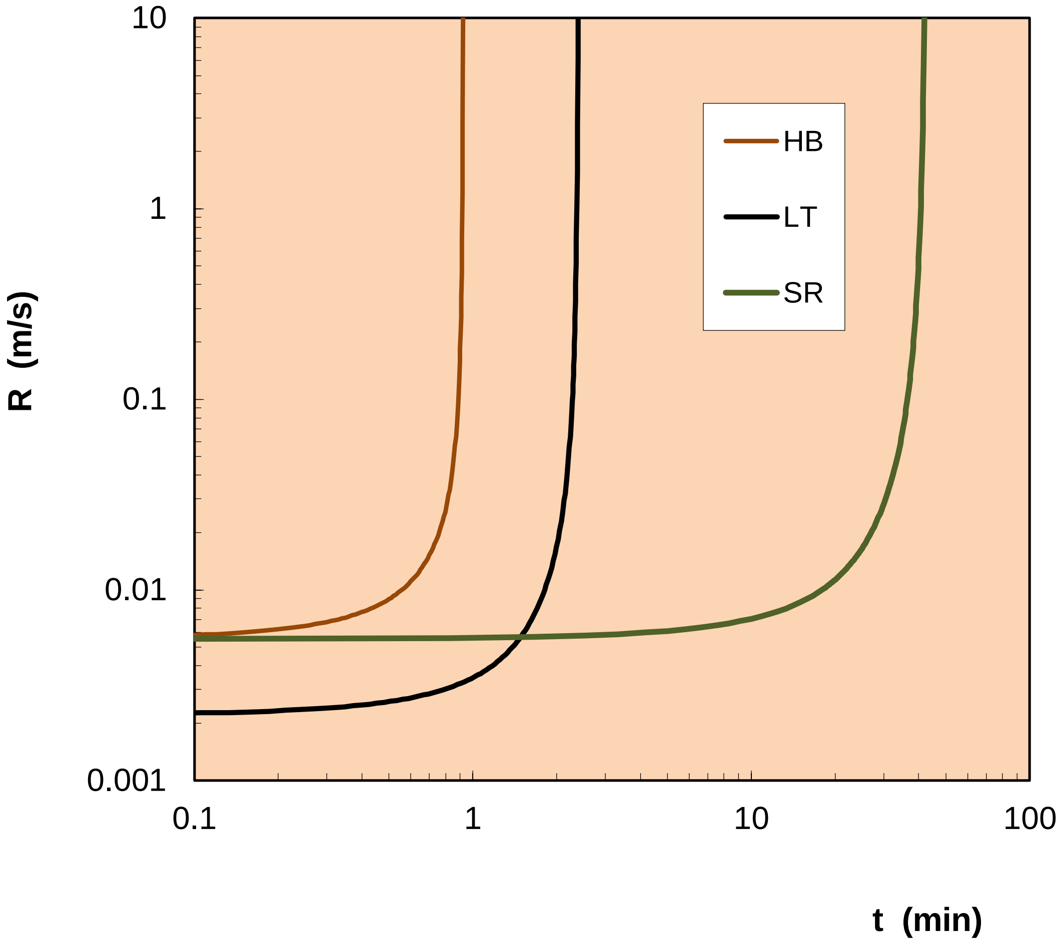
α=20°
δ=30°



α=30°
δ=30°

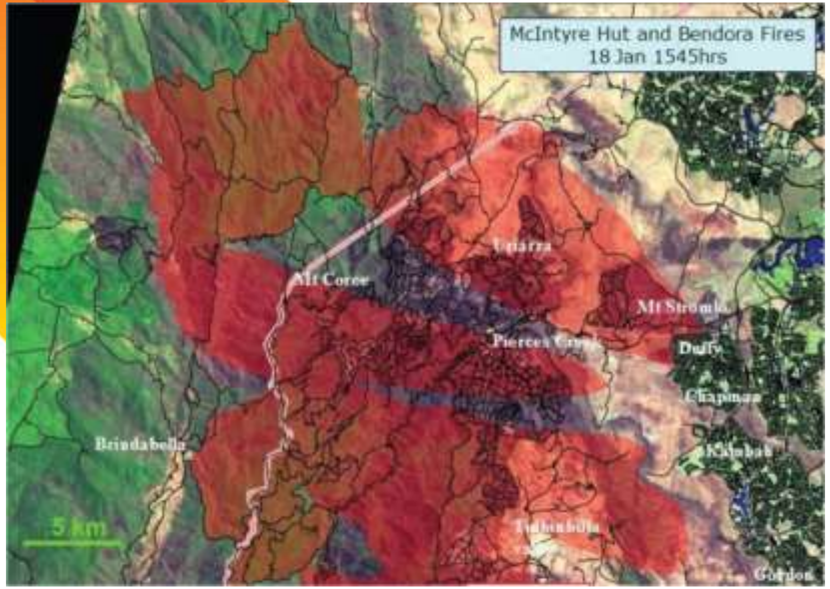




HB	Herbaceous
LT	Litter
SR	Shrub

Viegas DX, 2006. Parametric Study of an Eruptive Fire Behaviour Model. Int. J. Wildland Fire. 15(2):169-177.

Merging of two oblique fronts



Canberra 2003

In the Fire Laboratory the merging of two lines making a small angle between them produced a fire spread similar to what was observed in Canberra.

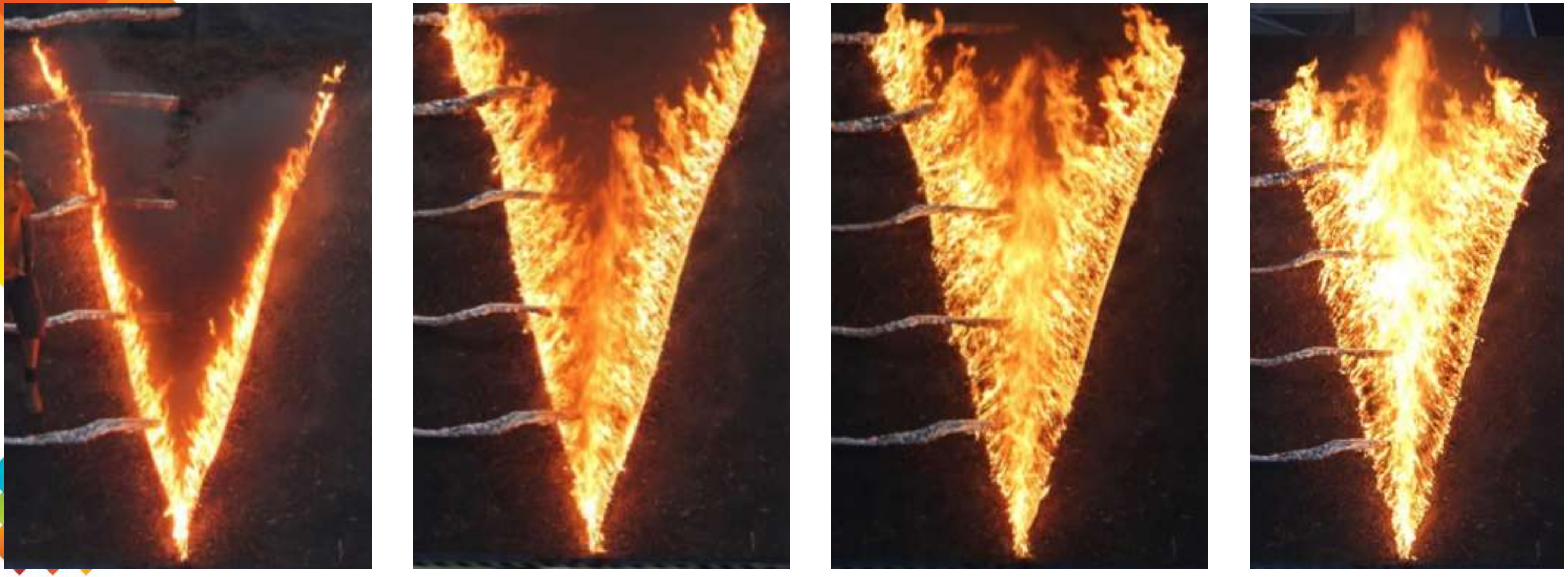
Laboratory test

Test CF-08

$\theta = 30º$

$\alpha = 30º$

Laboratory simulation of two merging fronts



Δt=3 s

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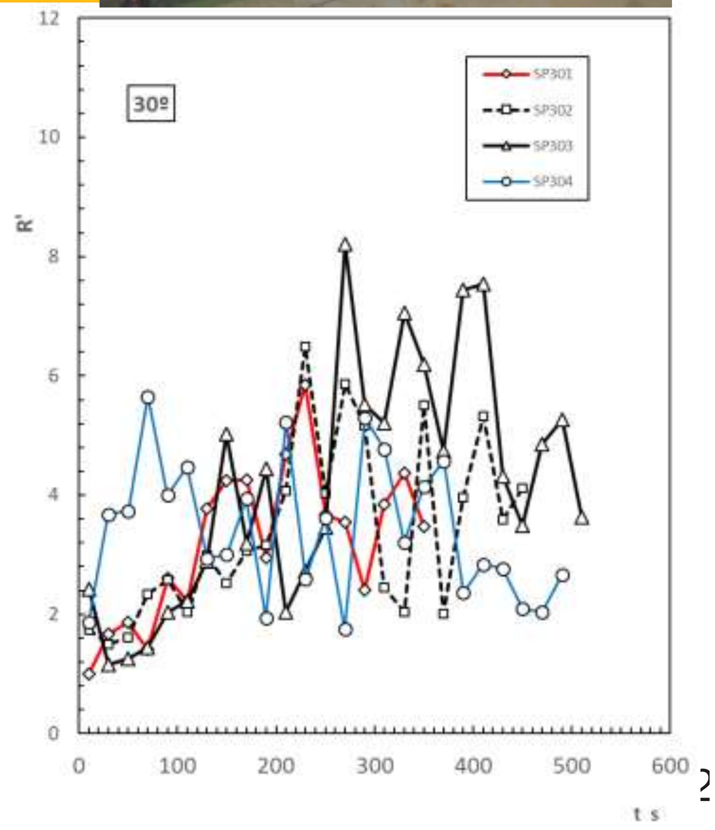
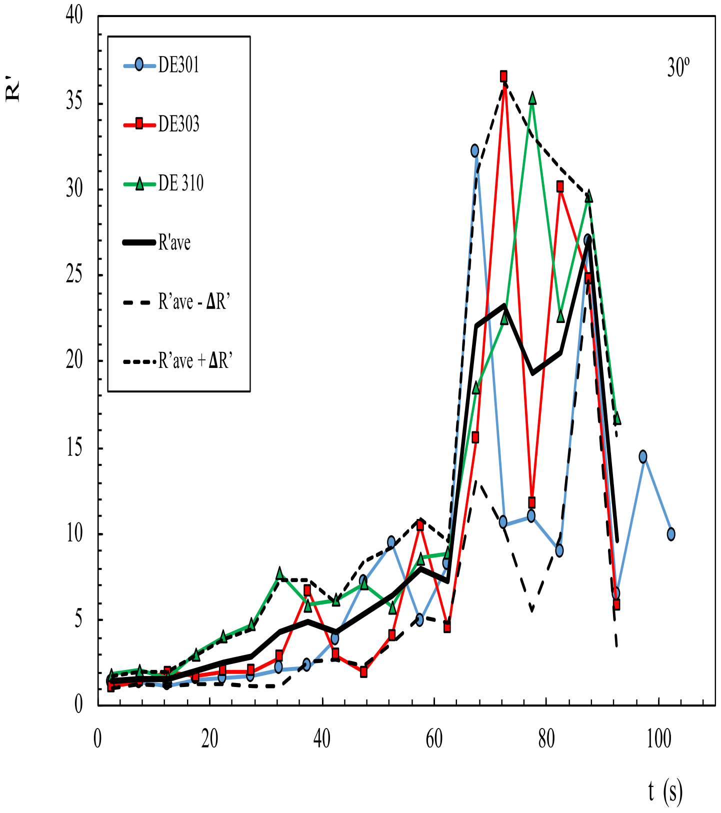
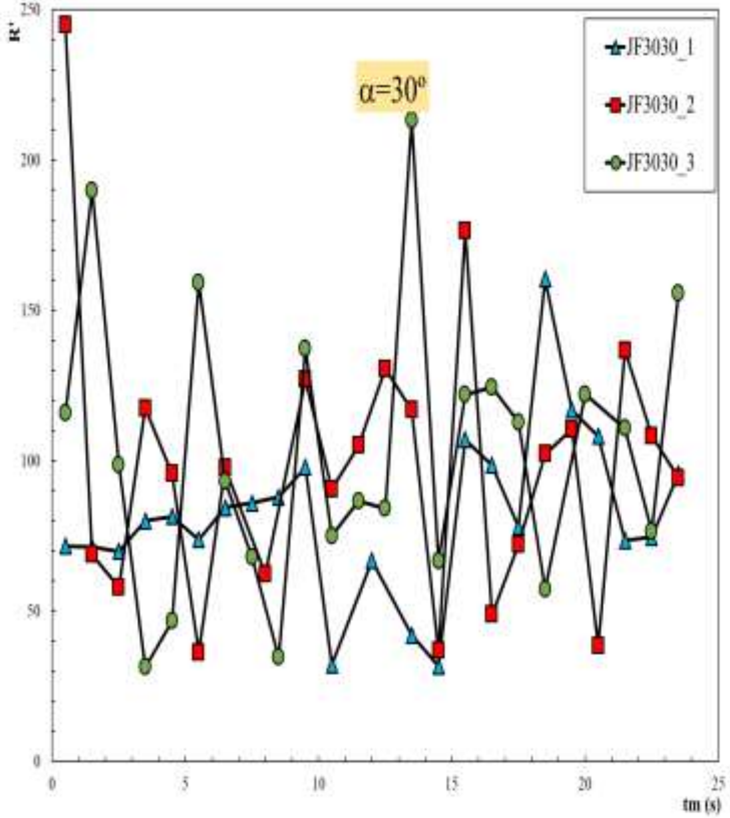
Viegas *et al*., 2012. Study of the Jump Fire. Part 1. Int. J. Wildland Fire. 21:843-856.

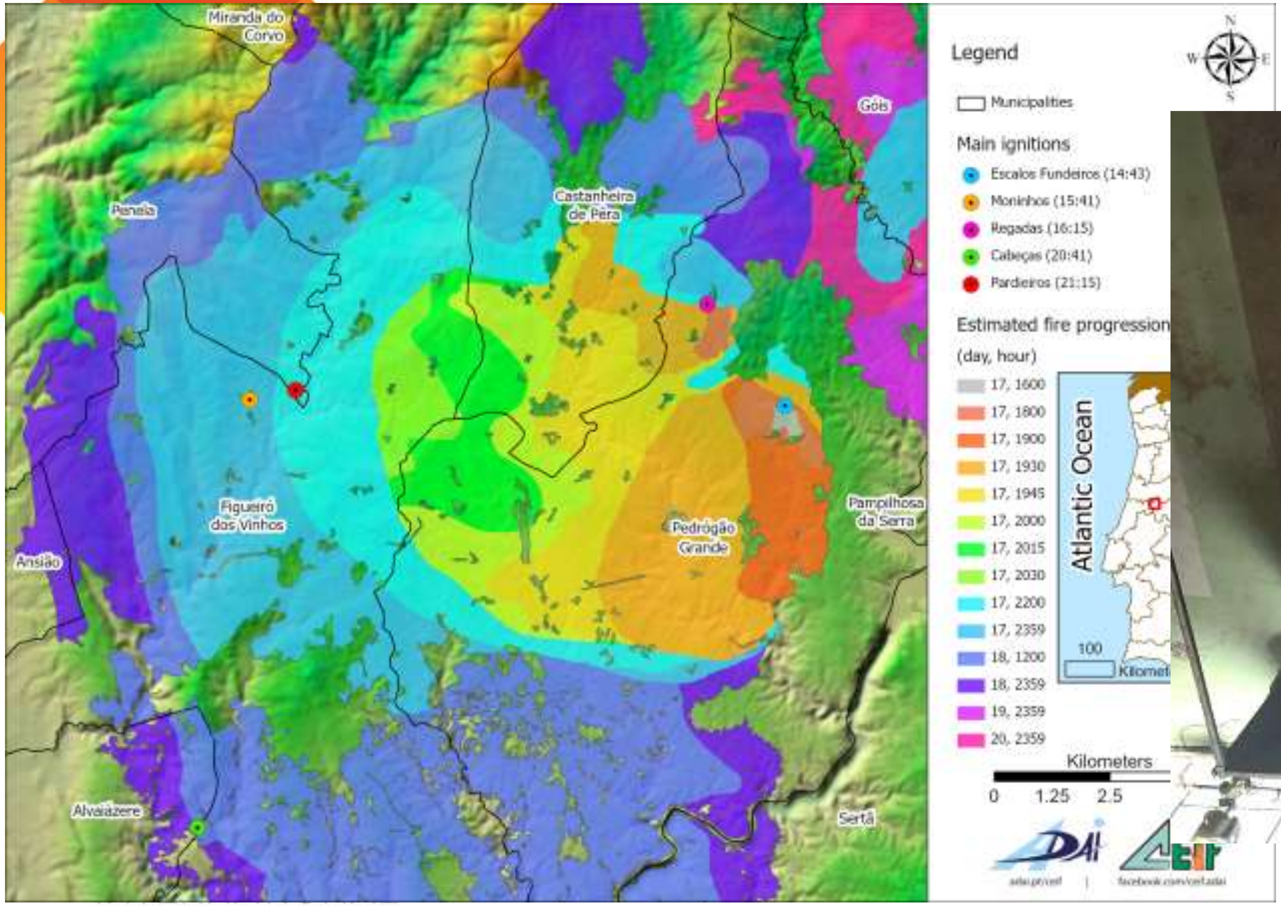
Raposo *et al*., 2018. Analysis of the physical processes associated with junction fires at laboratory and field scales. Int. J. Wildland Fire. 27:52-68.


30º
SP301
SP302
SP303
SP304
R'
t s


DE301
DE303
DE 310
R'ave
R'ave - ΔR'
R'ave + ΔR'
30º
R'
t (s)


JF3030_1
JF3030_2
JF3030_3
α=30º
R'
tm (s)

The case of Pedrógão Grande Fire (Portugal, June 2017, 66 fatalities)



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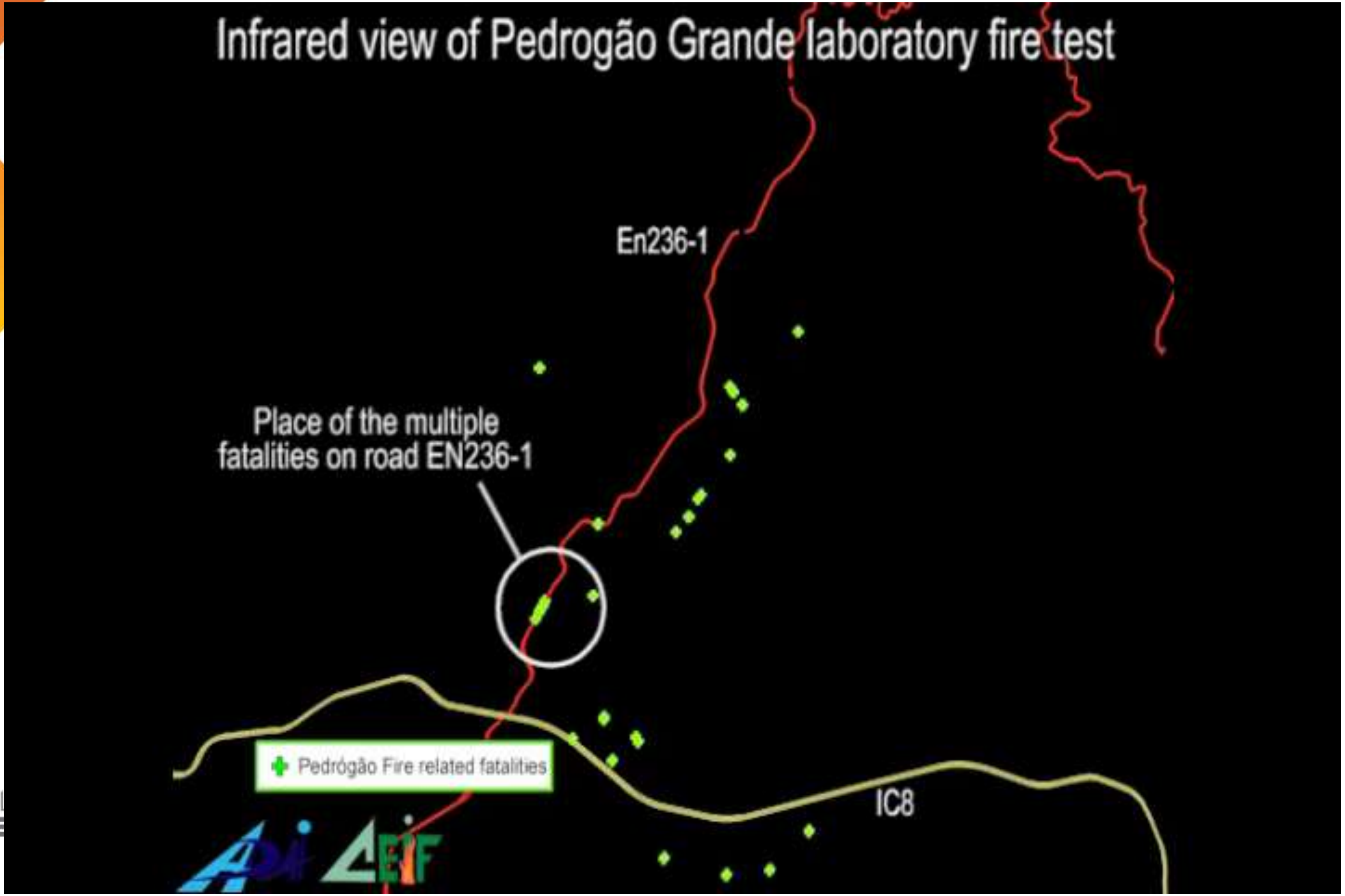
Infrared view of Pedrogão Grande laboratory fire test
En236-1
Place of the multiple fatalities on road EN236-1
Pedrógão Fire related fatalities
IC8


S.JOÃO

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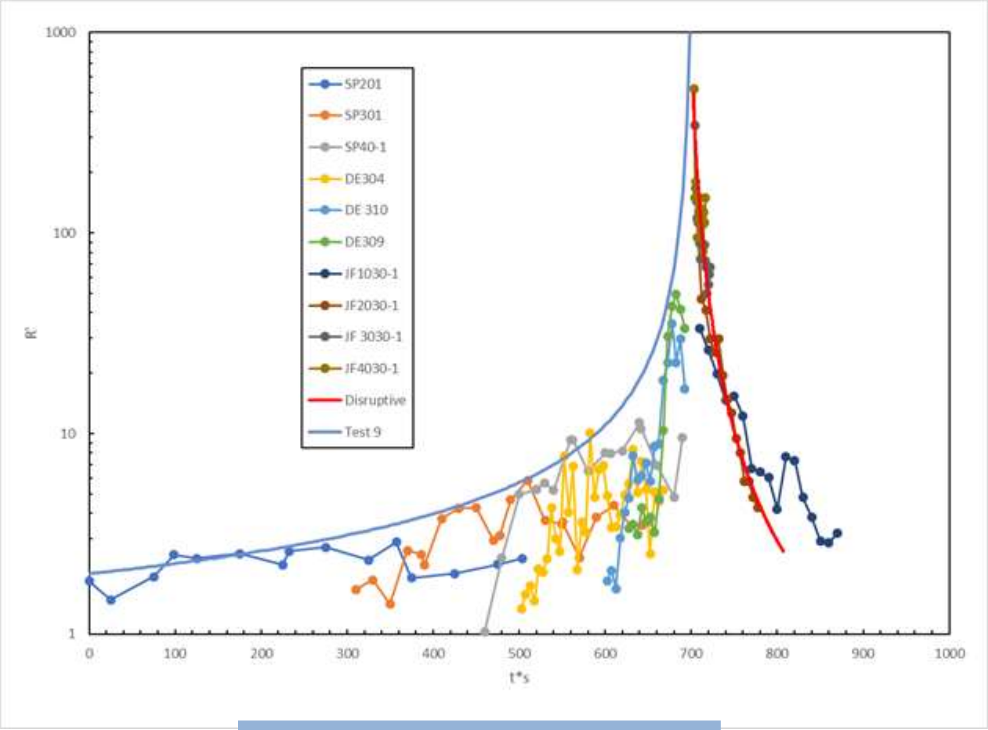
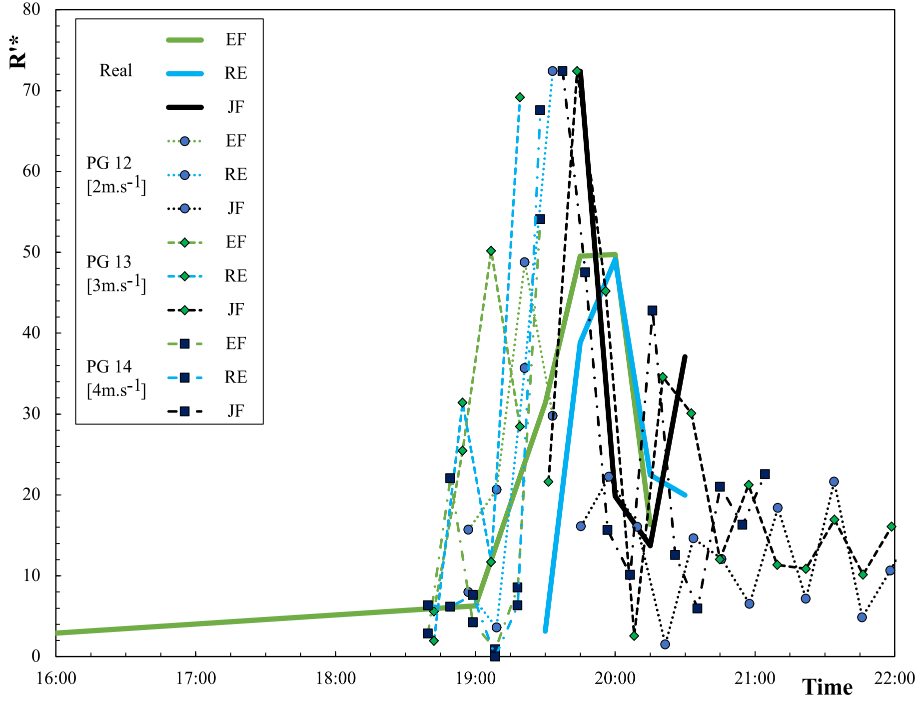
Acceleration and deceleration of the head fire

Joint analysis of the acceleration and the deceleration of the fire

$$\frac{dR'}{dt'} = {a'_1}^{\frac{1}{b_1}} b_1 a'_2 (R' - 1)^{1-\frac{1}{b_1}} R'^{b_2}$$



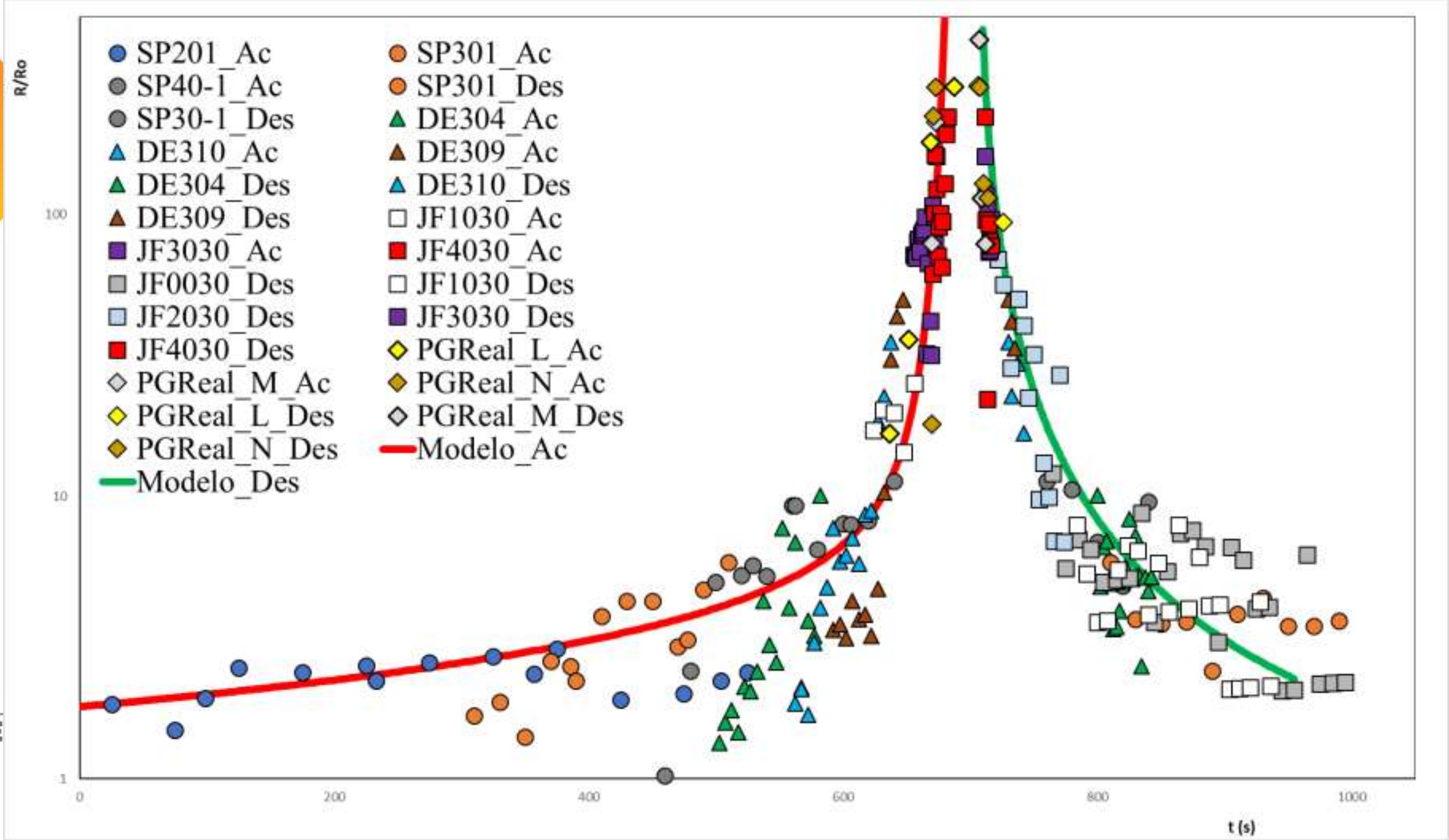
Laboratory experiments



Fire of Pedrógão Grande

Cont. Sci.&Tech. FF Management

Mathematical model of acceleration and deceleration



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Cont. Sci.&Tech. FF Management

4. Technical Solutions

- In our research we also work on technical solutions to enhance the capacity to prevent and suppress fires, and to be protected from them.
- Some of them do not require very advanced technology in order to be easily applied, while others make use of recent advances in science and technology.

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Water sprinkler system to protect the village of Travessas (Arganil)

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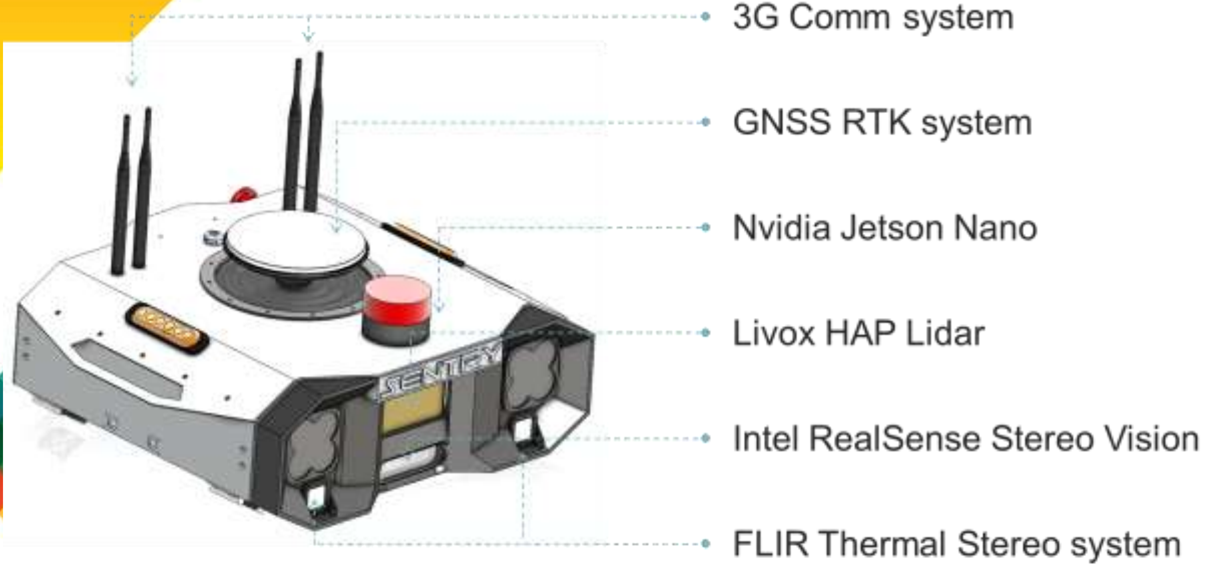
Sentry

ADAI FIELD TECH LAB.

F4F FOREST for FUTURE

Advanced automation system for forestry vehicles



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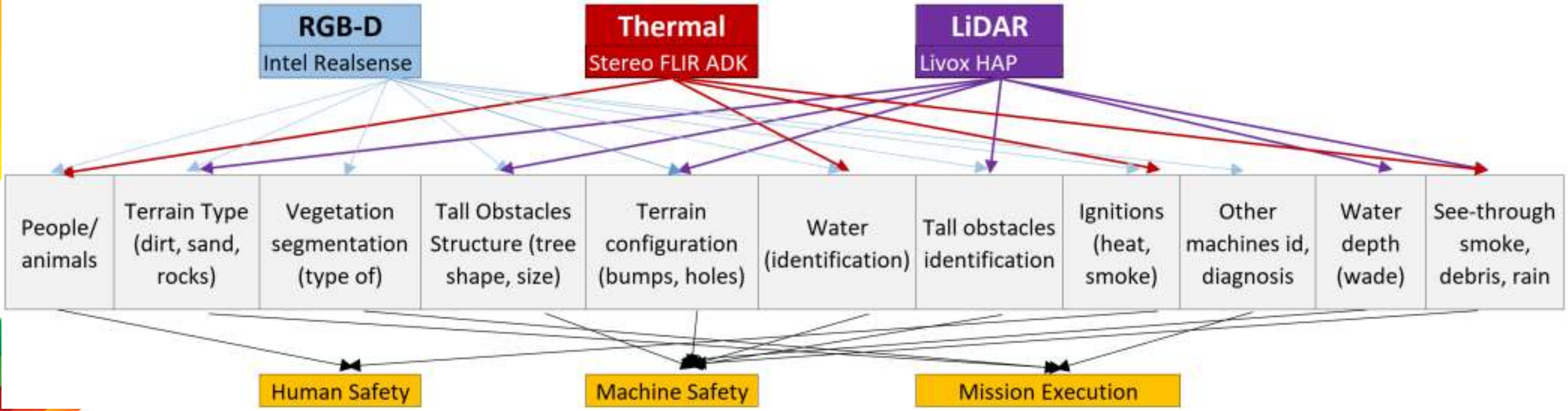
Sentry

Perception and autonomous navigation of heavy machinery in unstructured environments

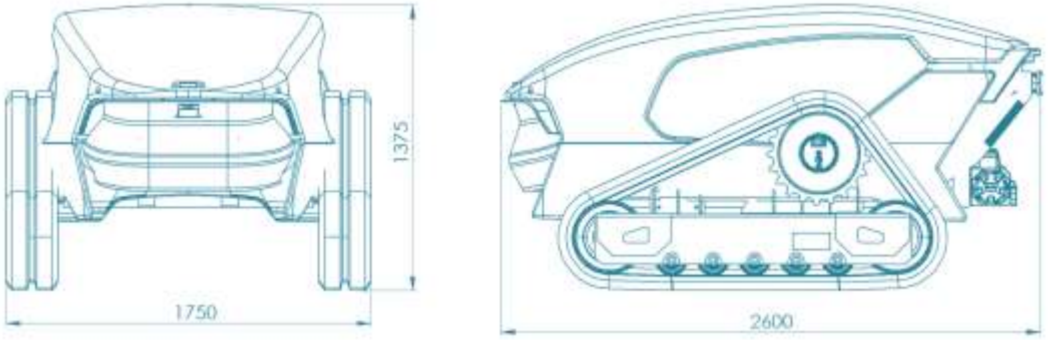


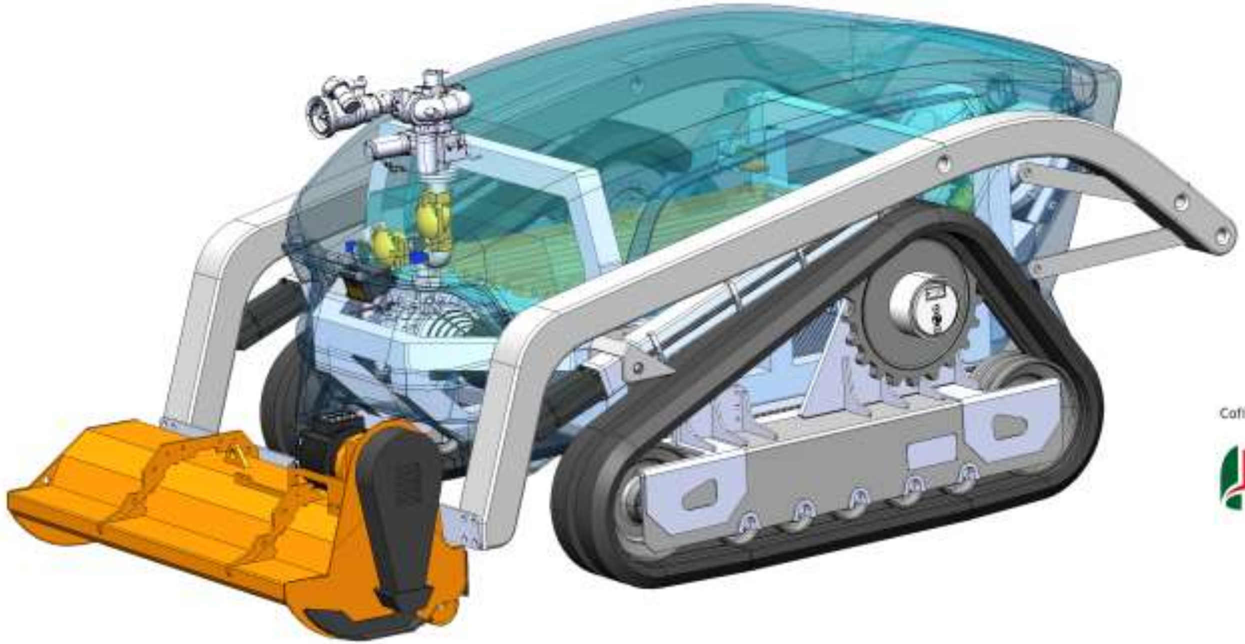
Ad hoc multimodal and redundant sensor architectures to ensure reliable functioning and safe operation under highly challenging scenarios, such as the presence of dense mist, smoke, debris, different lighting, lack of distinctive visual references, rough terrain, etc.

Spartan

Multi-Role All Terrain Electric Vehicle

- Embedded sensors for autonomous/remote operation
- Modular robotic platform
- 1000 Litres water capacity
- Electric drive and tools
- 30 kW drive motors
- 60 kWh battery pack





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ADAI FIELD TECH LAB.

E- FOREST

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Firefighting UAV

- Autonomous operation with flame detection
- 24 min flight endurance
- 200 l/min water flow

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Eye in the Sky

Using High-Altitude Balloons for Decision Support in Wildfire Operations

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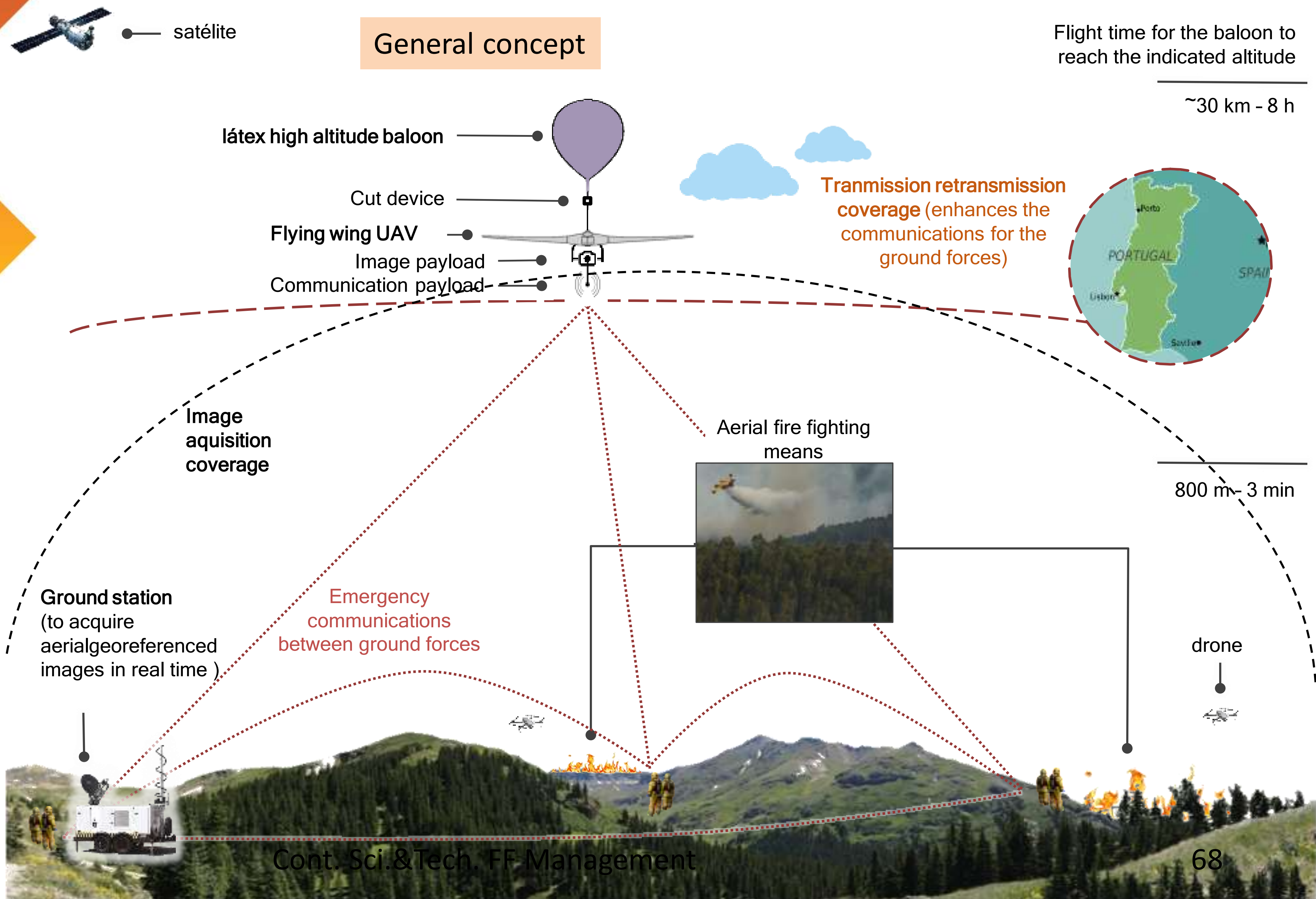
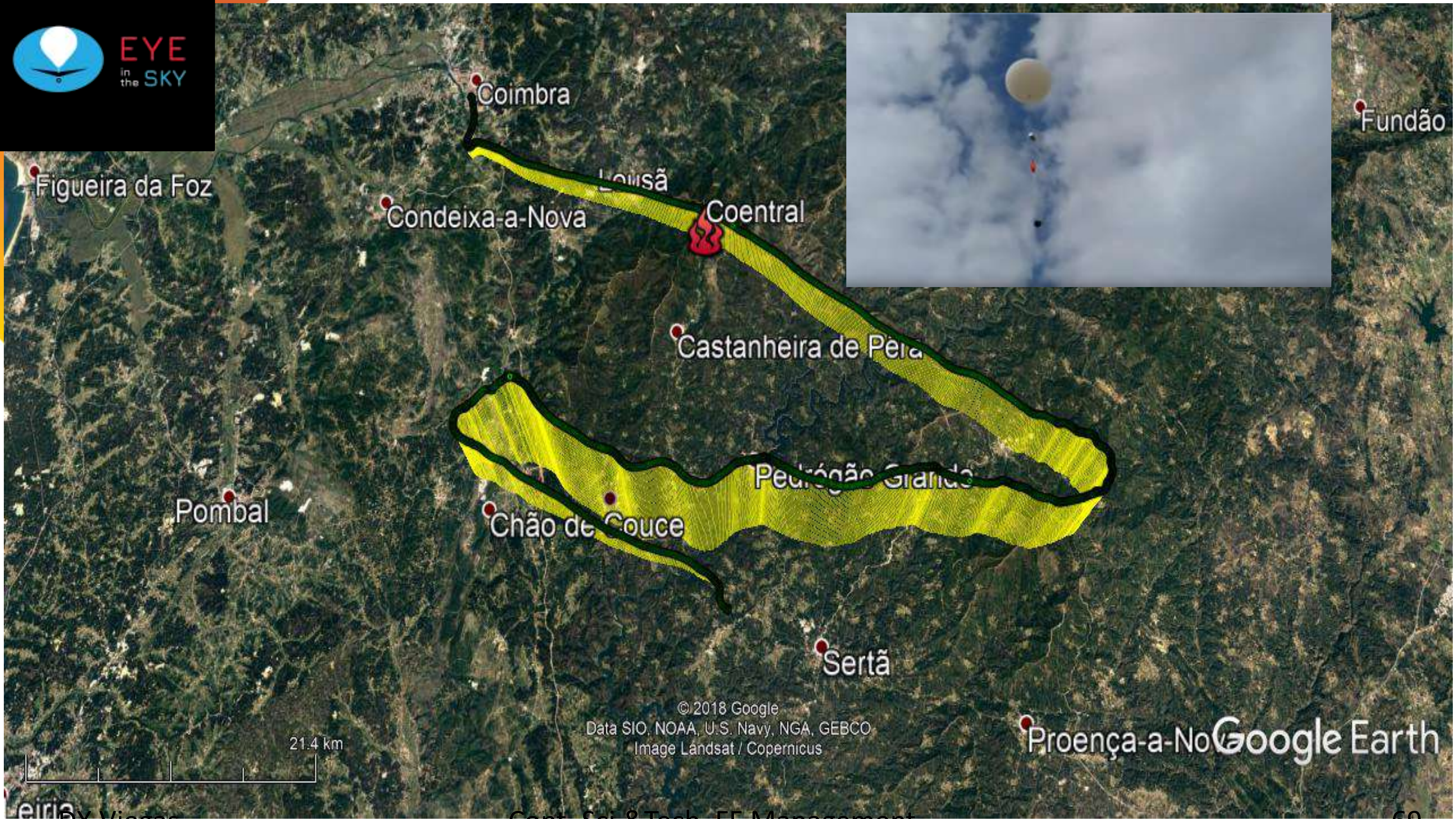
General concept




Coimbra
Figueira da Foz
Lousã
Condeixa-a-Nova
Coentral
Fundão
Castanheira de Pera
Pedrógão Grande
Pombal
Chão de Couce
Sertã
© 2018 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
21.4 km
Proença-a-No
Google Earth

EYE in the SKY

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5. Conclusion

- At the University of Coimbra in Portugal we are developing a research program on different aspects of wildfire management since 1985.
- In the scope of various National and EU projects we have proposed innovative ideas and technical solutions to address the problem.
- Some of these concepts are already part of the common legacy to science and to practical applications, namely in the area of fire safety.

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- The inclusion of sound science in a good framework of risk assessment, considering all aspects of wildfire risk, is the best way to address the problem.
- A good organization and interaction of all the persons and agencies involved in risk management – including the citizens - is also necessary to minimize the impact of extreme wildfire events.

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Contribution of Science and Technology to Forest Fire Management

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