

Sparky

A Fire Modelling Framework for Operational Applications

Joe McNorton

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**THE STATE OF
WILDFIRES** PROJECT



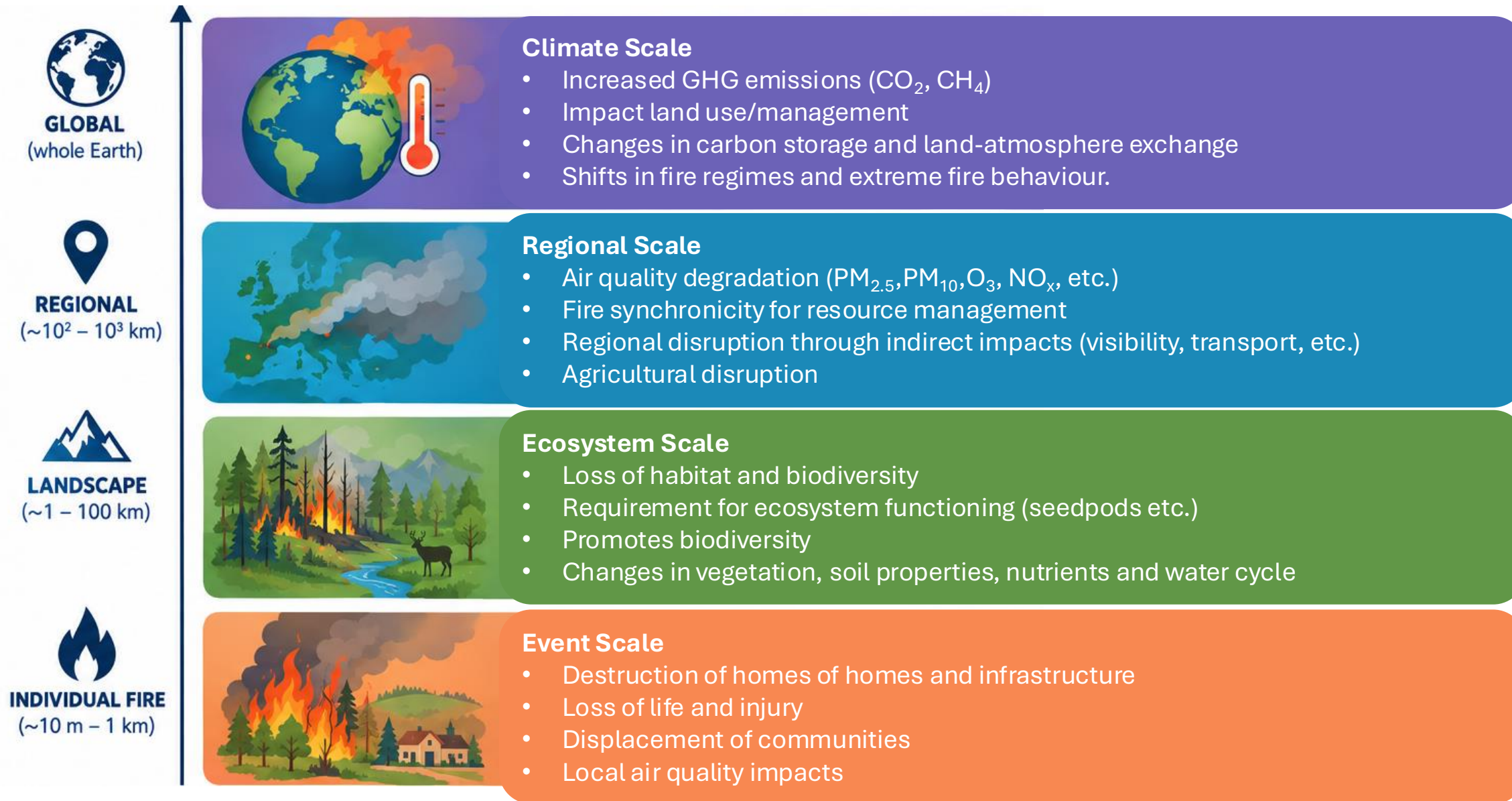
**Emergency
Management Service**



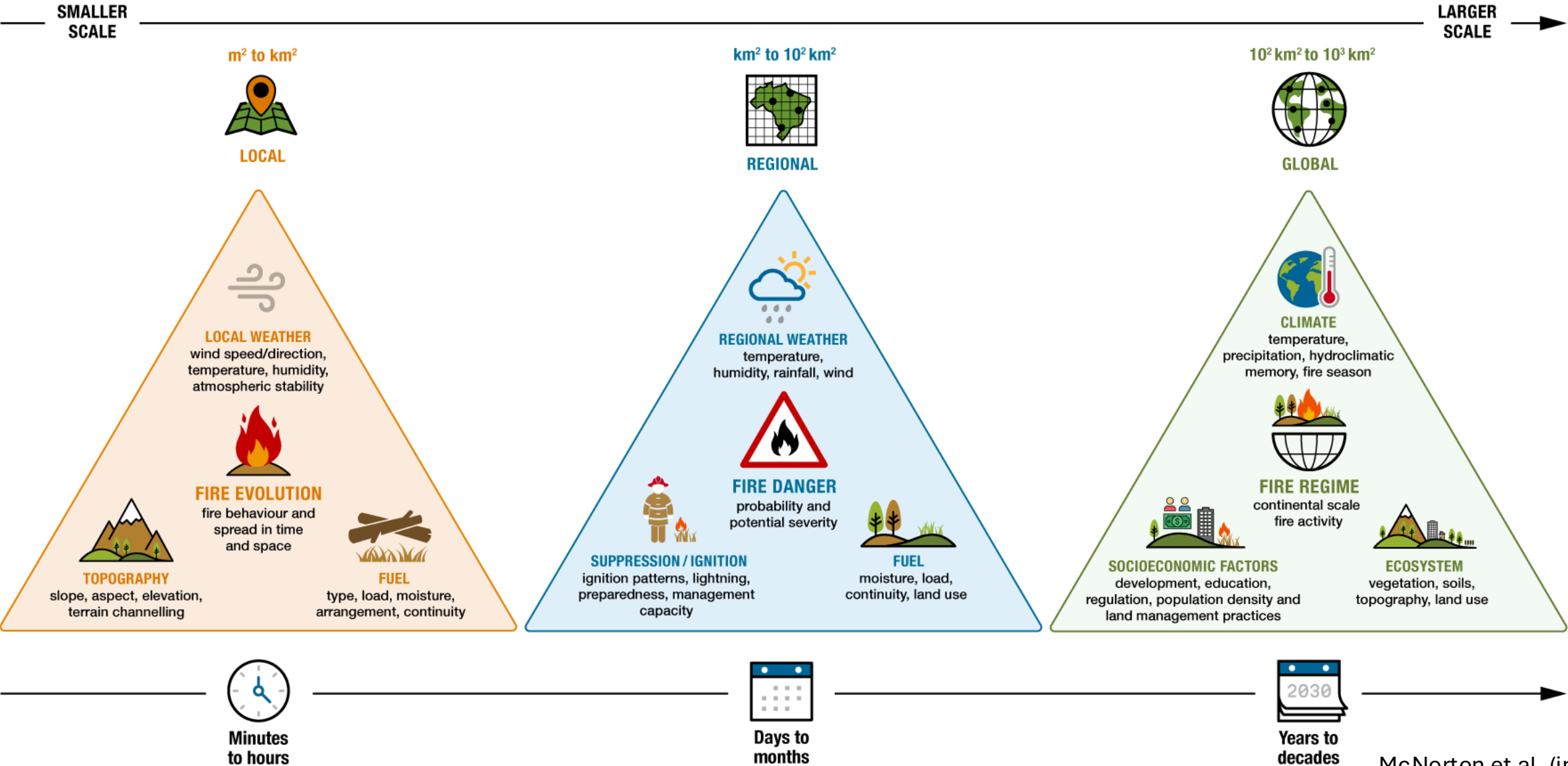
CoFlame

Copernicus Fire and
Land-Atmosphere
Modelling of Emissions

Wildfires and Their Impacts



Assessing the Drivers - Similarities and Differences Across Scales



McNorton et al. (in prep)

Key Questions for Societal Benefit



Key Question for Applications: Can Forecasts be informative?



Decadal-Annual
Land Management
And Planning



Monthly-Week
Early Resource
Mobilisation

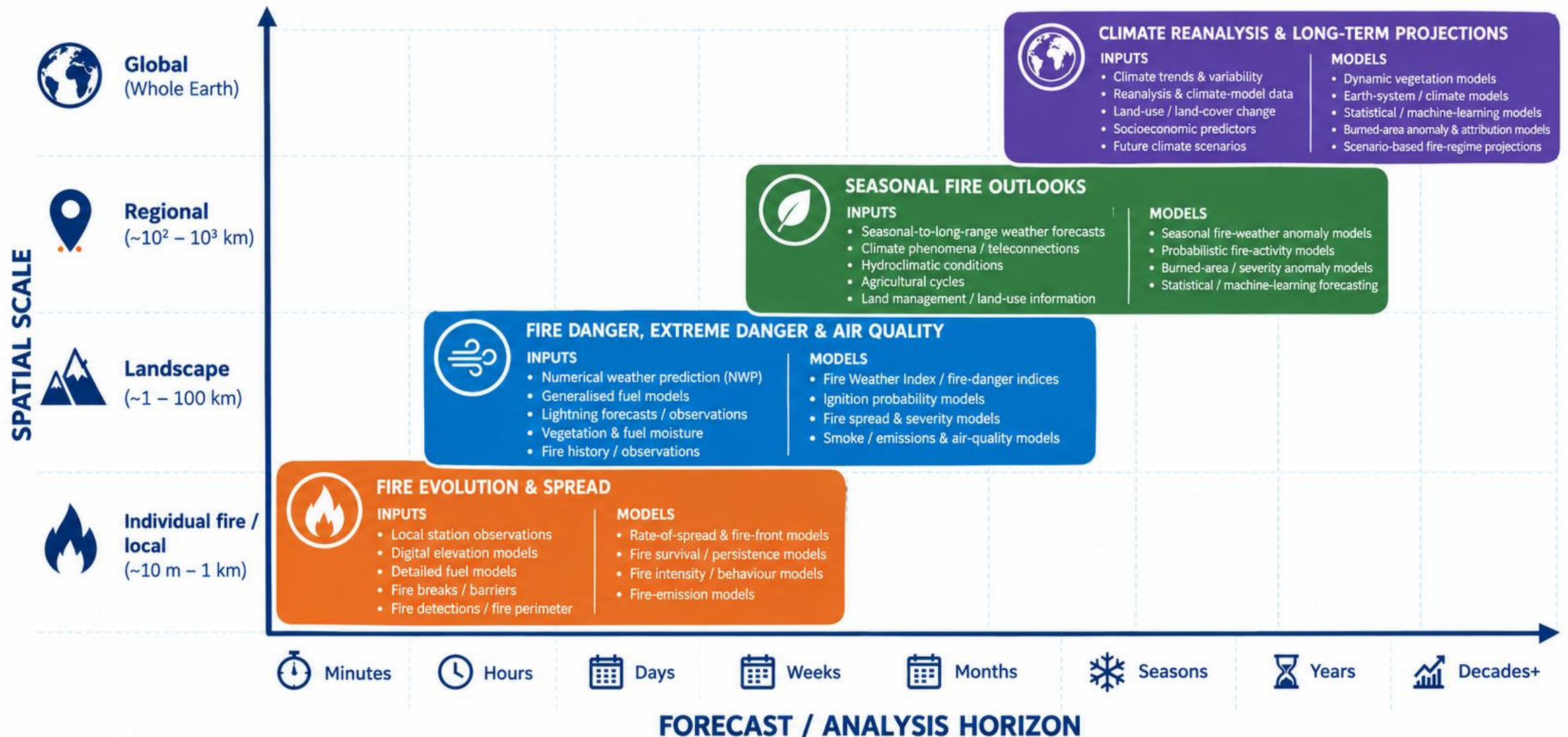


Week-Day
Mitigation Efforts (closures,
pre-emptive burns etc.)



Day-Hour
Suppression Efforts
Evacuations

The Models to Answer the Questions



The Current State of Wildfire Modelling at ECMWF and Beyond



Fire evolution modelling

High-cost physical rate-of-spread models, typically not viable in real-time.



Fire emissions modelling

GFAS MODIS FRP informed emissions from a single daily overpass with persistence or decay assumption and imposed diurnal cycle.



Fire danger forecasts

Fire Weather Index as a metric for fire severity based on 4 weather variables and no consideration of fuel and ignitions.



Seasonal forecasts

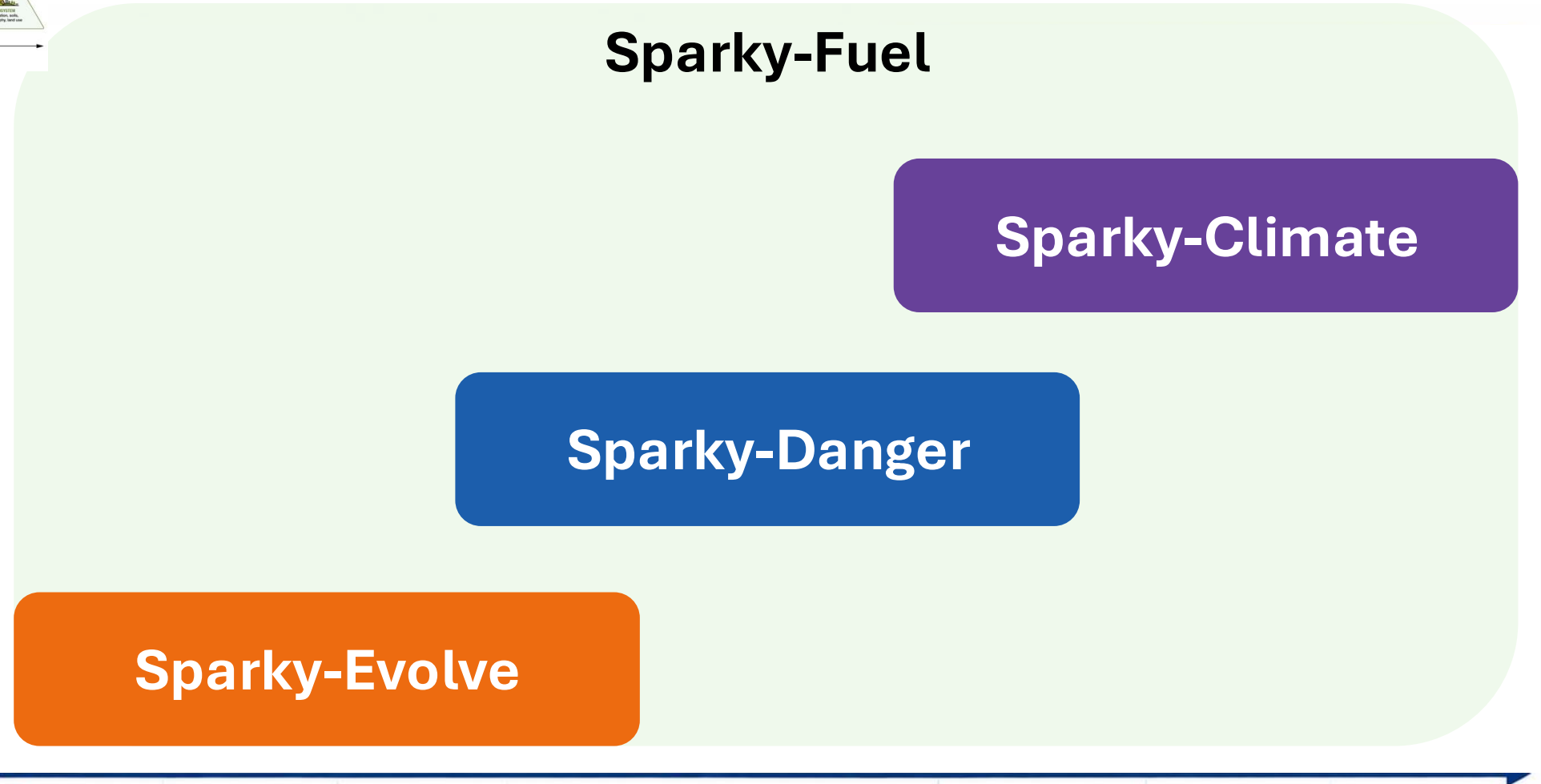
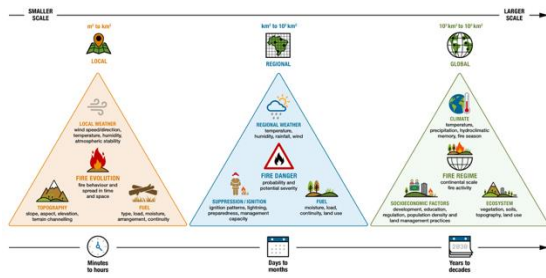
Seasonal FWI, only applicable as a weather-informed anomaly.



Climate projections & reanalysis

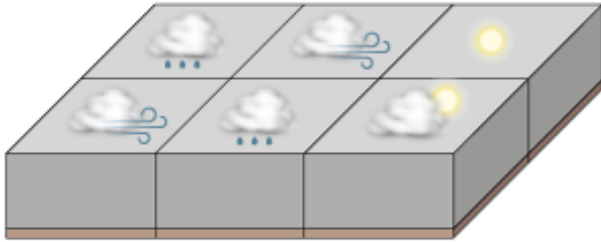
Fire-enable physical dynamic vegetation models, which are not designed to capture trends in fire behaviour.

The Sparky Model Framework



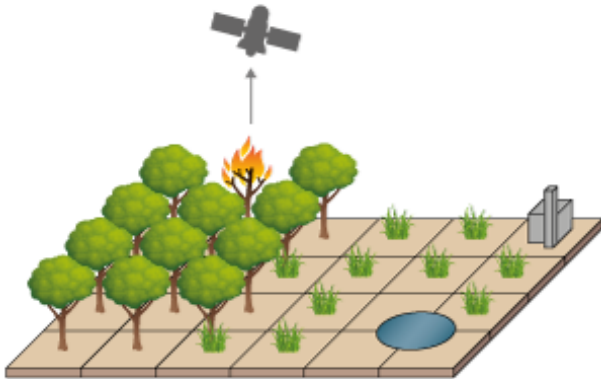
Low resolution

Meteorological and land surface IFS forcing (9km)



Observations

Active fires, Burnt area,
FRP (e.g. 0.25km)



Vegetation type, Fuel moisture (1km)	Sparky
1	1
2	1
3	1
4	1
5	1
6	1
7	1
8	1
9	1
10	1
11	1
12	1
13	1
14	1
15	1
16	1
17	1
18	1
19	1
20	1
21	1
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92	1
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94	1
95	1
96	1
97	1
98	1
99	1
100	1

Sparky-Fuel

Sparky-Danger

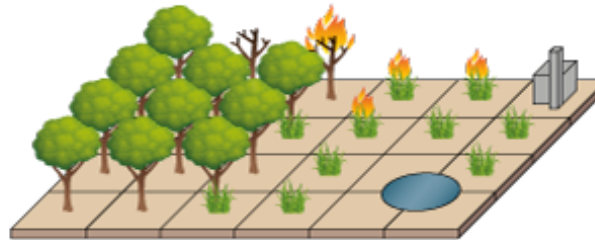
Fire Danger using meteorology, slope, flammability and fuel (1km)



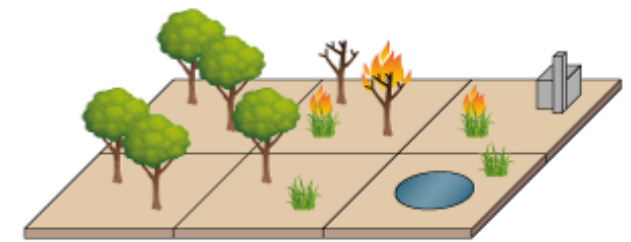
SPARKY
THE ECMWF FIRE MODEL

Sparky-Evolve

(~7.5 minutes, 1km)

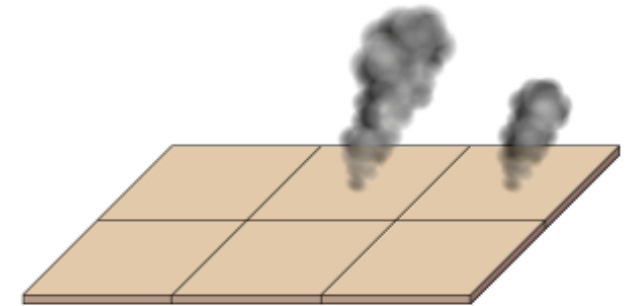


Returns burning, burnable, burnt and unburnable fraction per grid cell



Sparky-Climate

Trace gas and aerosol emissions for IFS (9km)



Sparky-Fuel and Why Fuel Matters?

BBC For you Home News Sport Weather iPlayer

NEWS

Home InDepth Israel-Gaza war War in Ukraine Climate UK World Business Politics Culture

Climate

Climate 'whiplash' linked to raging LA fires

THE CONVERSATION

Academic rigour, journalistic flair

Arts + Culture Business + Economy Education Environment Health Politics + Society Science + Tech World Podcasts Insights

LA fires show the human cost of climate-driven 'whiplash' between wet and dry extremes

Published: January 10, 2025 4:21pm GMT

Allison Dinner / EPA

Global Change Biology

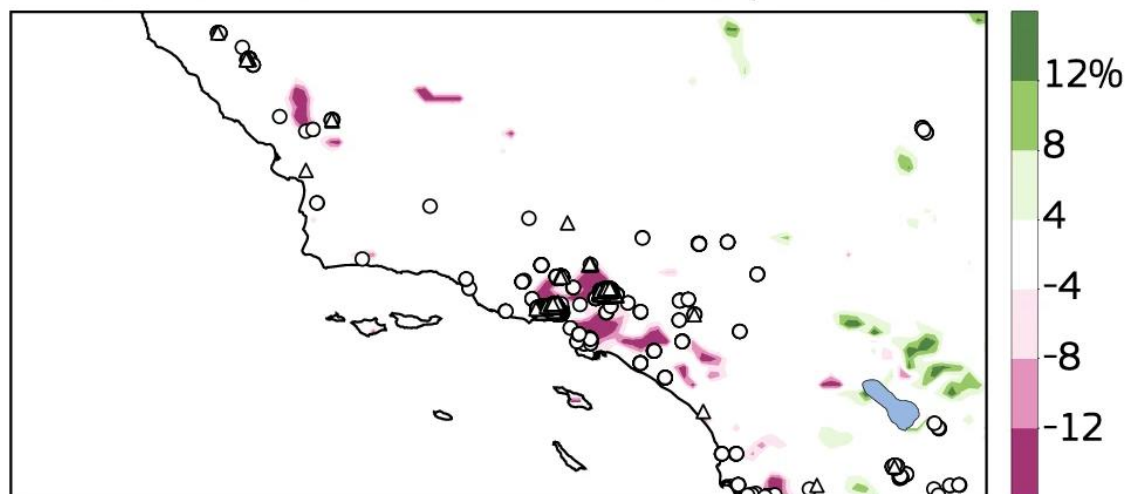
SCIENCE BEHIND THE NEWS | Free Access

Increasing Hydroclimatic Whiplash Can Amplify Wildfire Risk in a Warming Climate

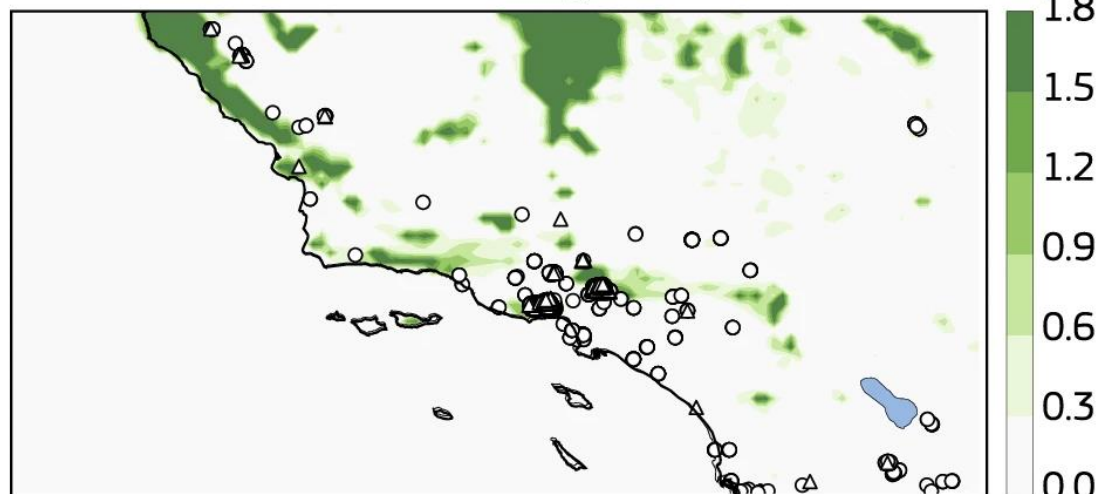
Daniel L. Swain, John T. Abatzoglou, Christine M. Albano, Manuela I. Brunner, Noah S. Diffenbaugh, Crystal Kolden, Andreas F. Prein, Deepti Singh, Christopher B. Skinner ... See all authors

First published: 07 February 2025 | <https://doi.org/10.1111/gcb.70075> | Citations: 1

Dead Fuel Moisture Content Anomaly 7-1-2025



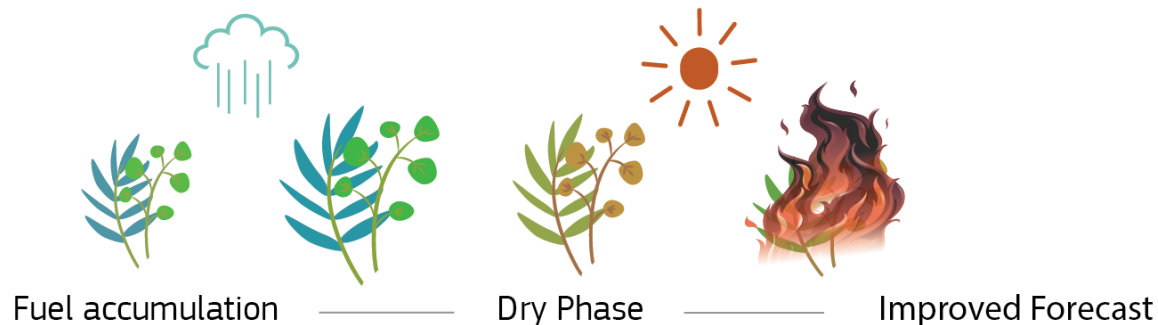
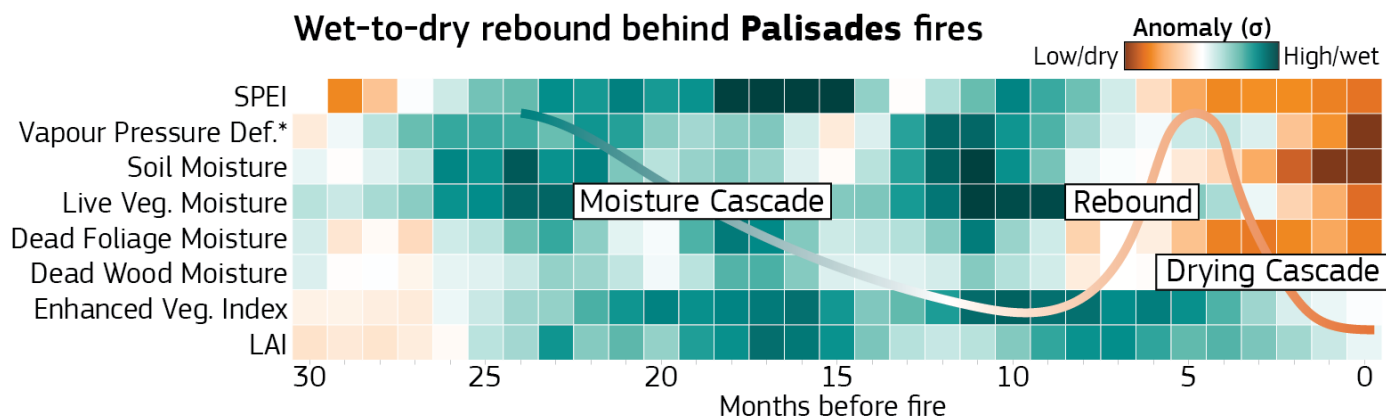
Total Fuel Load (kg m²) 7-1-2025



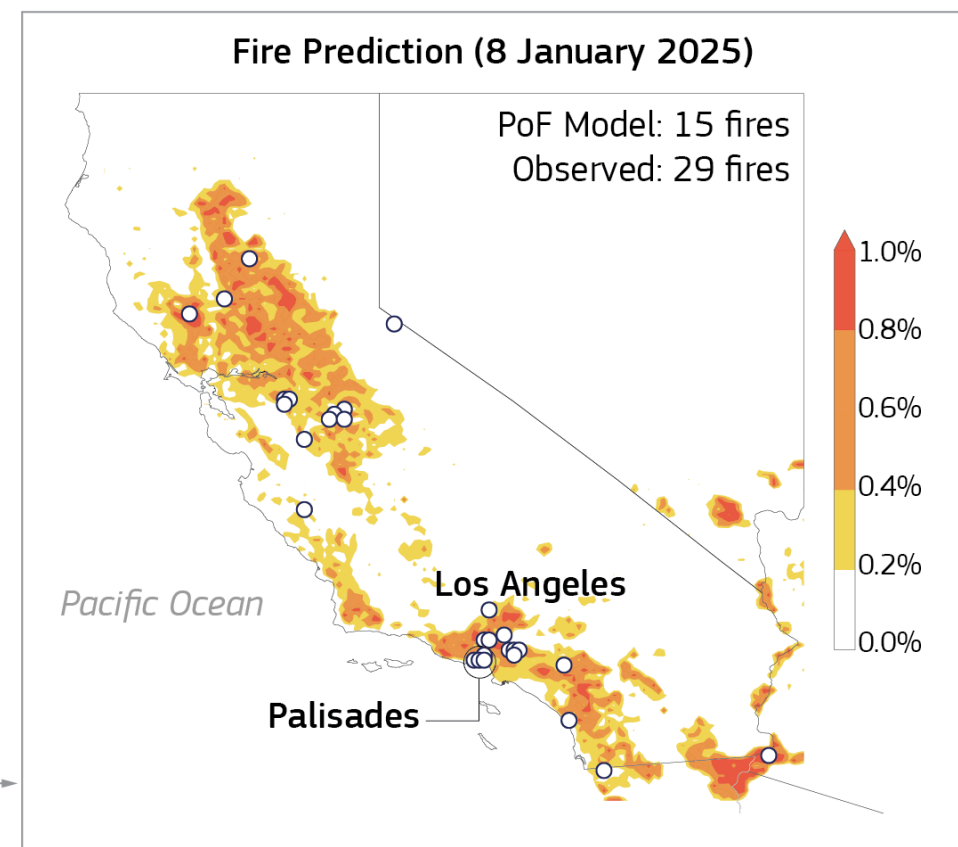
Fuel is dynamic not static

The Role of Hydroclimate Rebound in Extreme Fires

Wet-to-dry rebound behind **Palisades** fires



Fire Prediction (8 January 2025)



Global Change Biology

RESEARCH ARTICLE | [Open Access](#) | [©](#) [i](#) [s](#)

Hydroclimatic Rebound Drives Extreme Fire in California's Non-Forested Ecosystems

[This article relates to:](#)

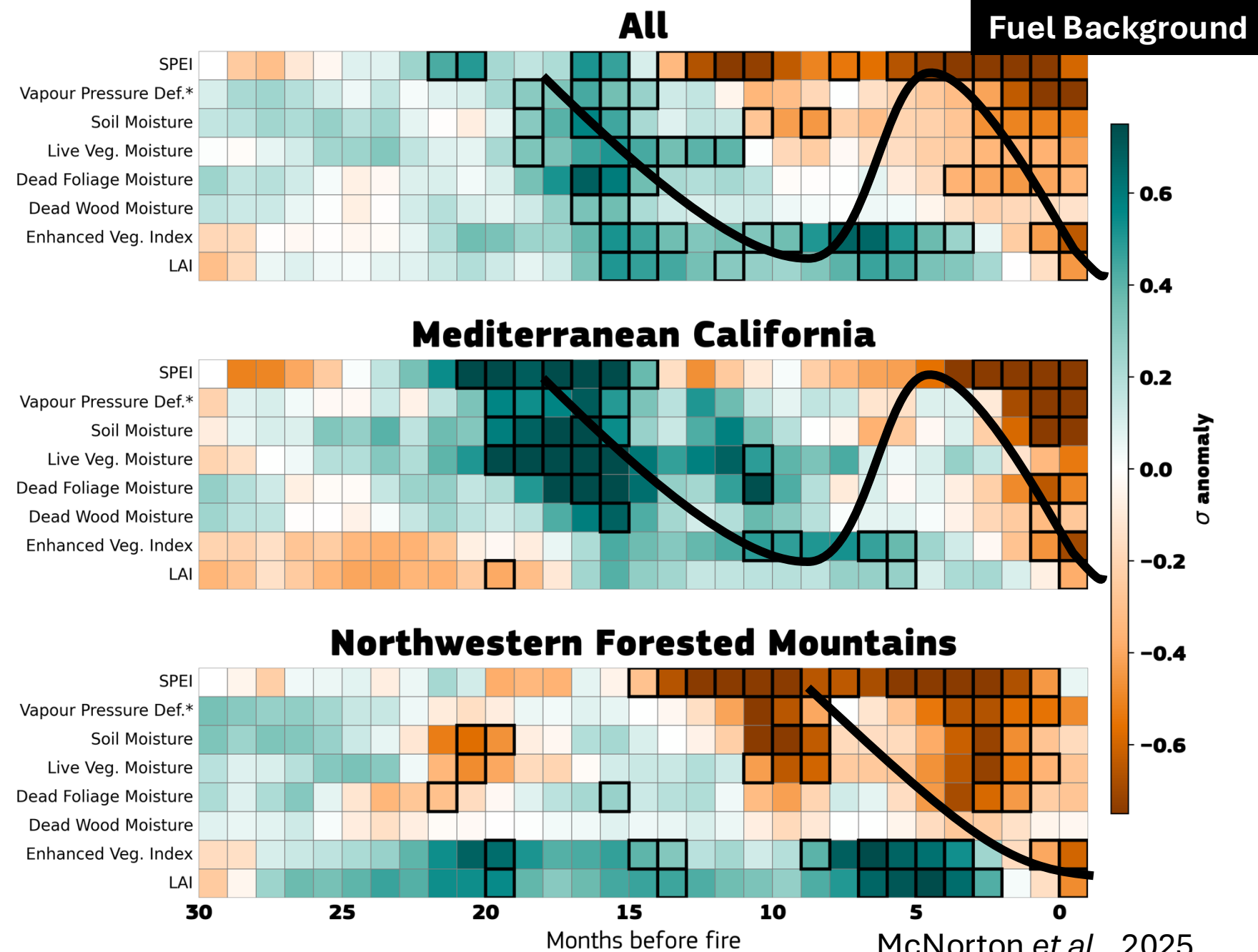
Joe McNorton [✉](#) Alberto Moreno Marco Turco Jessica Keune Francesca Di Giuseppe

Not all biomes...

FUEL LIMITED

Evidence for Hydroclimatic Rebound (Wet -> Dry)

FUEL ABUNDANT
No Clear Rebound
(Dry)

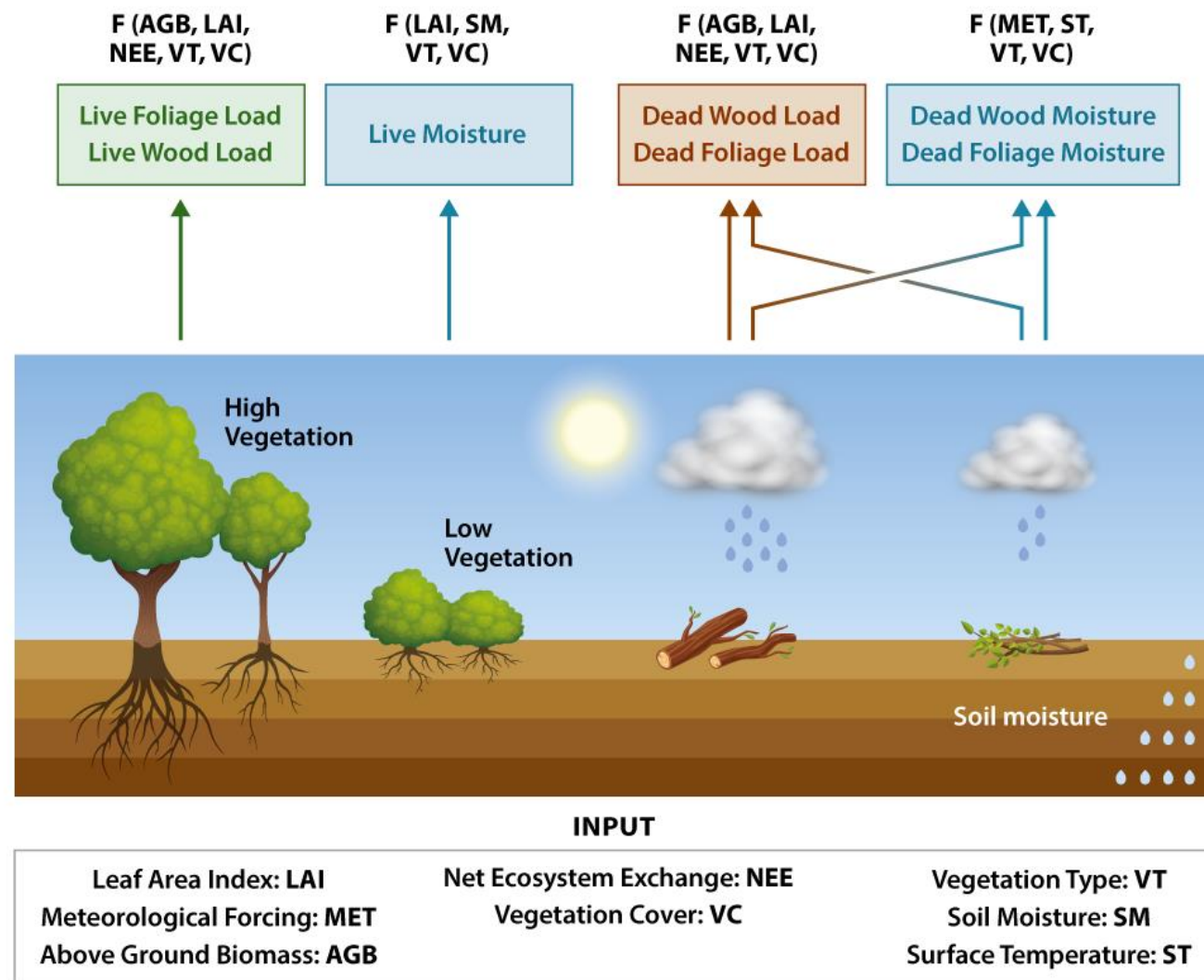


Sparky-Fuel

A global 9km dataset of fuel characteristics informed using:

- ESA-CCI AGB
- ESA-CCI LAI
- ERA-5
- IFS-Land Cover
- CAMS CO₂ inversions
- and more...

<https://xds.ecmwf.int/datasets/derived-fire-fuel-biomass>



Biogeosciences, 21, 279–300, 2024
<https://doi.org/10.5194/bg-21-279-2024>
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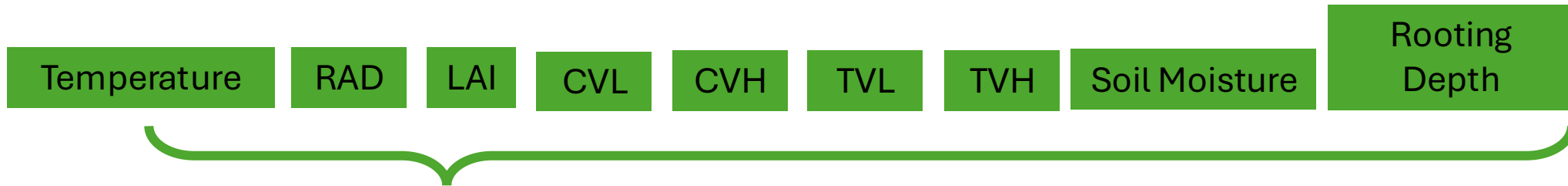


A global fuel characteristic model and dataset for wildfire prediction

Joe R. McNorton¹ and Francesca Di Giuseppe²

¹ECMWF, Reading, UK; ²ECMWF, Reading, UK

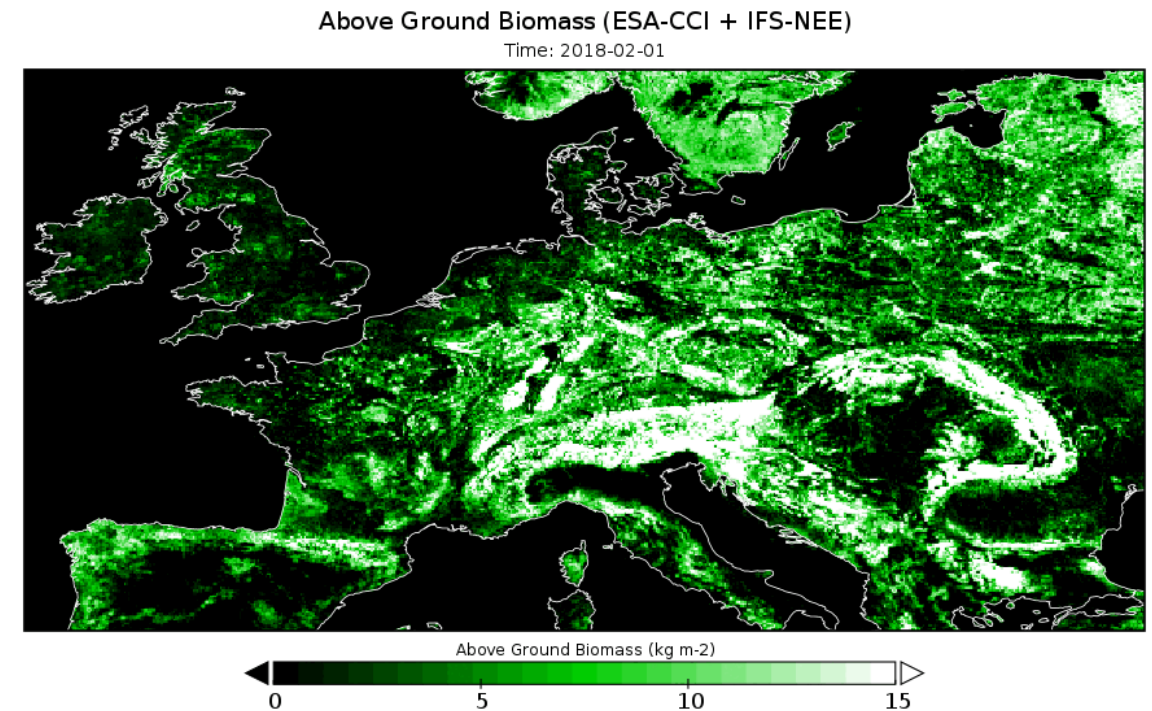
Sparky-Fuel Load



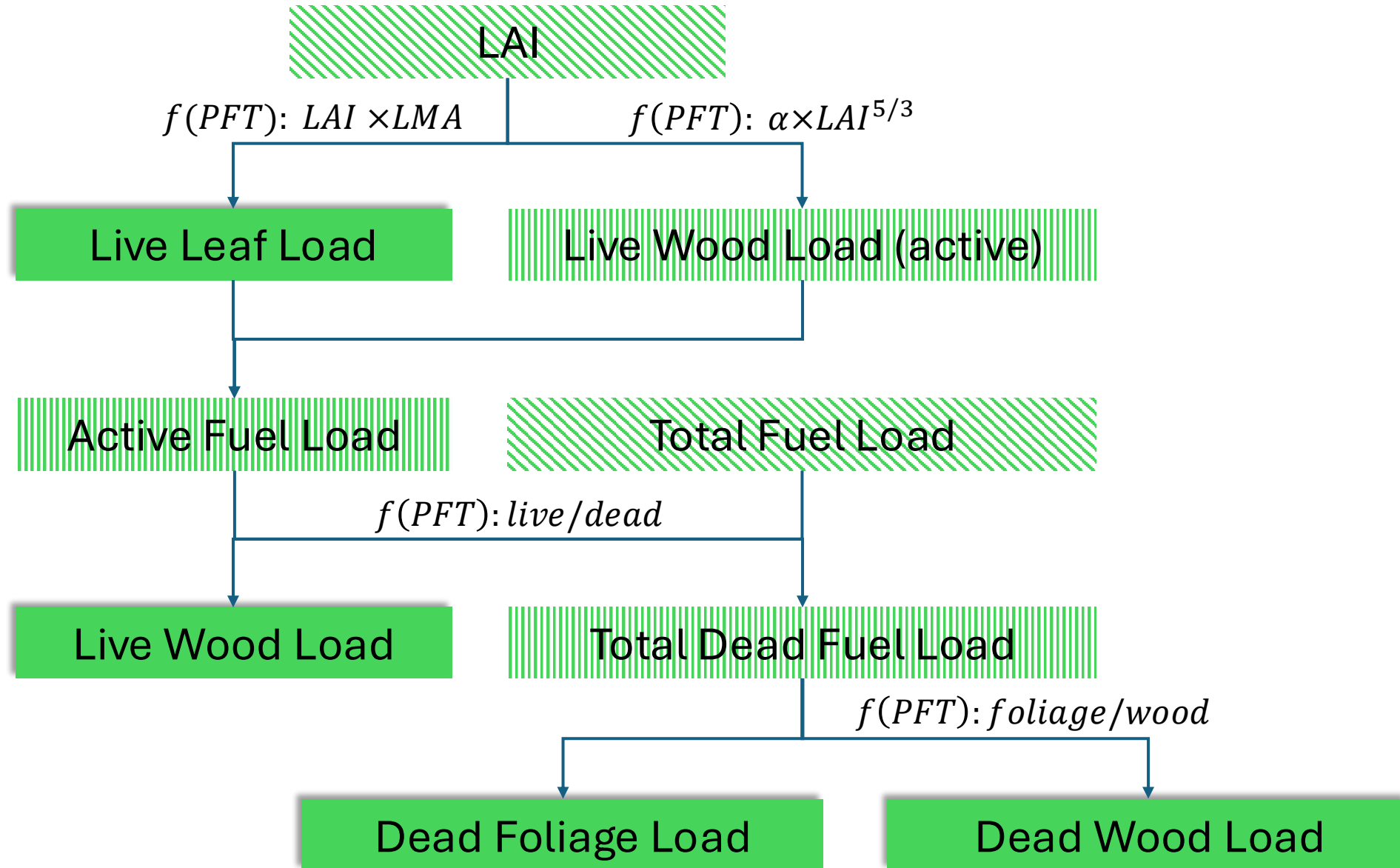
IFS – Ecland scheme (with BFAS)

$$\text{Fuel Load}_{t=x-1} + \text{NEE}_{t=x} = \text{Fuel Load}_{t=x}$$

Grid cell specific scaling applied annually between 0.1 and 10 based on $\text{ESA-CCI } \text{AGB}_{\text{year}} - \text{AGB}_{\text{year-1}}$



Sparky-Fuel Load



Sparky-Fuel Live Fuel Moisture Content

Curve fitting parameterisation based on LPMC-Globe observations, ERA5-Land multi-layer soil moisture and CONFESS Project LAI for 2010-2019.

Soil moisture is computed using the root zone depth fraction of each PFT.

Interrupted Forest	19	19
Mixed Forest	35	36
Deciduous Shrubs	36	30
Evergreen Shrubs	23	11
Bogs and Marshes	25	14
Semidesert	17	19
Irrigated Crops	24	4
Tundra	47	0
Tall Grass	27	19
Evergreen Broadleaf	25	14
Deciduous Broadleaf	24	7
Deciduous Needleleaf	26	7
Evergreen Needleleaf	26	6
Short Grass	35	4
Crops	24	4
	L1	L4
	L2	
	L3	

$$LFMC = \underbrace{LFMC_{max}}_{\text{Maximum LFMC}} - A e^{-(\underbrace{\alpha SM}_{\text{Dormant Moisture Uptake}} + \underbrace{\beta LAI}_{\text{Drought Resistance}} + \underbrace{\gamma SM LAI}_{\text{Growing Season Uptake}})}$$

Vegetation Type	$LFMC_{max}$	A	α	β	γ
Crops	110.8	1500.9	27.2	0.00	0.0
Short Grass	197.4	119.7	0.2	0.23	0.5
Evergreen needleleaf trees	132.6	65.3	1.9	0.00	1.2
Deciduous broadleaf trees	131.5	78.7	0.0	0.00	3.8
Mixed Crops	165.8	148.2	4.3	0.00	0.6
Deciduous shrubs	158.8	131.0	3.5	0.00	1.7
Broadleaf Savannah	242.3	237.9	1.8	0.03	0.0

Sparky-Fuel Dead Fuel Moisture Content

Adaptation of Nelson model (2000) for
1- , 10- , 100- , 1000- h fuels.

Forced by operational IFS or ERA5-Land

$$DFMC_t = DFMC_{t-1} + rainfall + evap./cond.$$

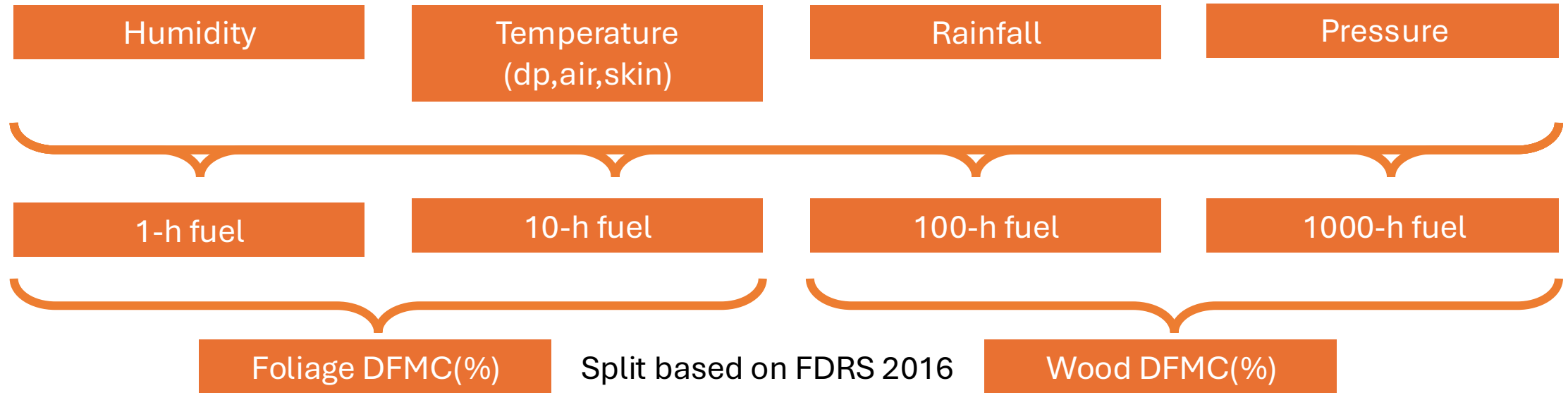
$$dM_{R,1-h} = \max\{0.85, 0.96(1 - e^{-0.6R})dt\}$$

$$dM_{R,10-h} = \max\{0.6, 0.32(1 - e^{-0.6R})dt\}$$

$$dM_{R,100-h} = \max\{0.4, 0.11(1 - e^{-0.6R})dt\}$$

$$dM_{R,1000-h} = \max\{0.32, 0.04(1 - e^{-0.6R})dt\}.$$

$$evap. or cond. = \left[\frac{0.662h_c \left(\frac{Pr}{Sc}\right)^{0.667}}{\rho c_a P_b a} \right] (p_s - P_d) \text{ (Nelson eq. 15)}$$



Sparky-Fuel Live Fuel Moisture Content

Curve fitting parameterisation based on LFMC-Globe observations, ERA5-Land multi-layer soil moisture and CONFESS Project LAI for 2010-2019.

Soil moisture is computed using the root zone depth fraction of each PFT.

	Crops	Short Grass	Evergreen Needleleaf	Deciduous Needleleaf	Deciduous Broadleaf	Evergreen Broadleaf	Tall Grass	Tundra	Irrigated Crops	Semidesert	Bogs and Marshes	Evergreen Shrubs	Deciduous Shrubs	Mixed Forest	Interrupted Forest
L1	24	35	26	26	24	25	27	47	24	17	25	23	23	19	19
L2	41	38	39	38	38	34	27	45	41	31	34	36	36	35	35
L3	31	23	29	29	31	27	27	8	31	33	27	30	30	36	36
L4	4	4	6	7	7	14	19	0	4	19	14	11	11	10	10

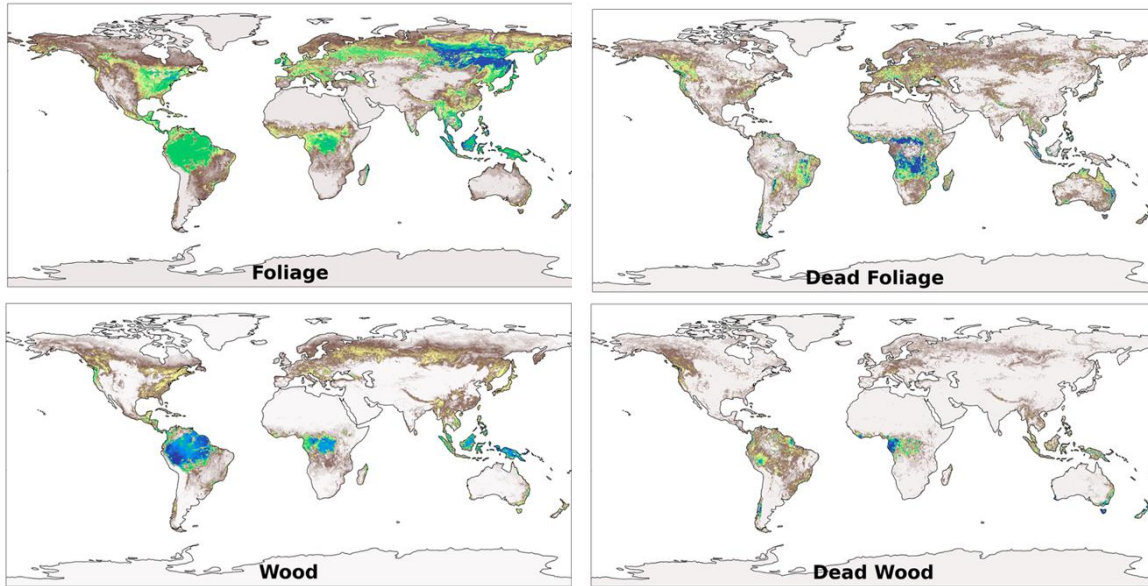
$$LFMC = LFMC_{max} - A e^{-(\alpha SM + \beta LAI + \gamma SM LAI)}$$

Maximum LFMC
 Dormant Moisture Uptake
 Drought Resistance
 Growing Season Uptake

Vegetation Type	$LFMC_{max}$	A	α	β	γ
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Sparky-Fuel

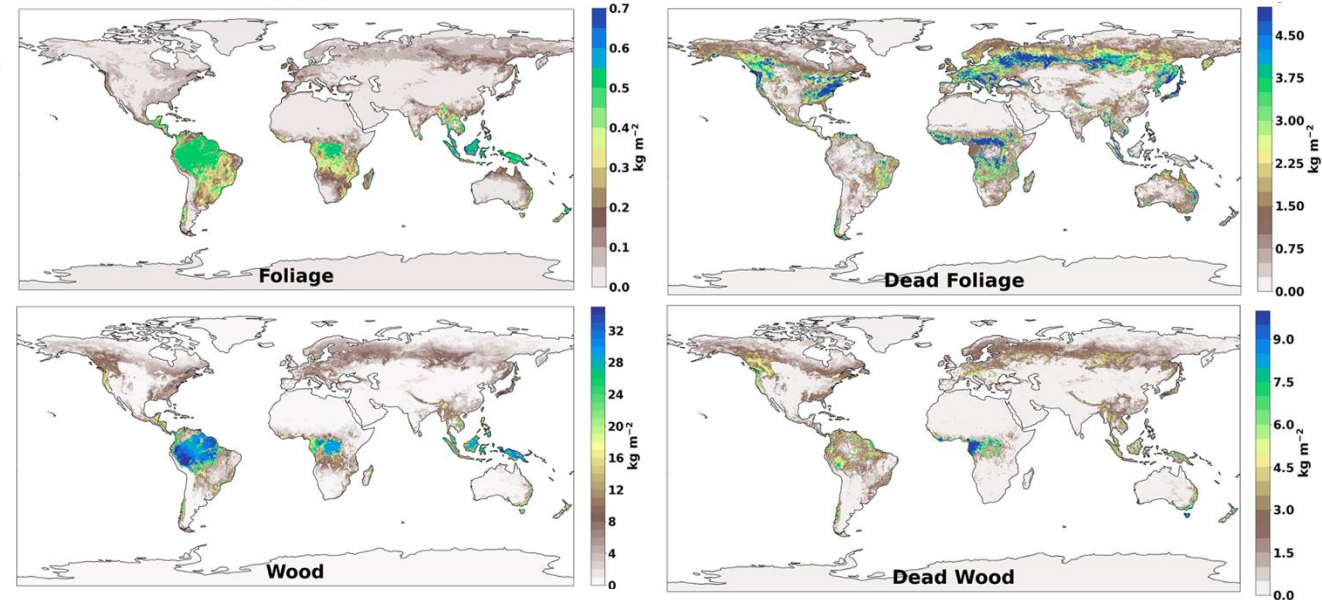
JJA



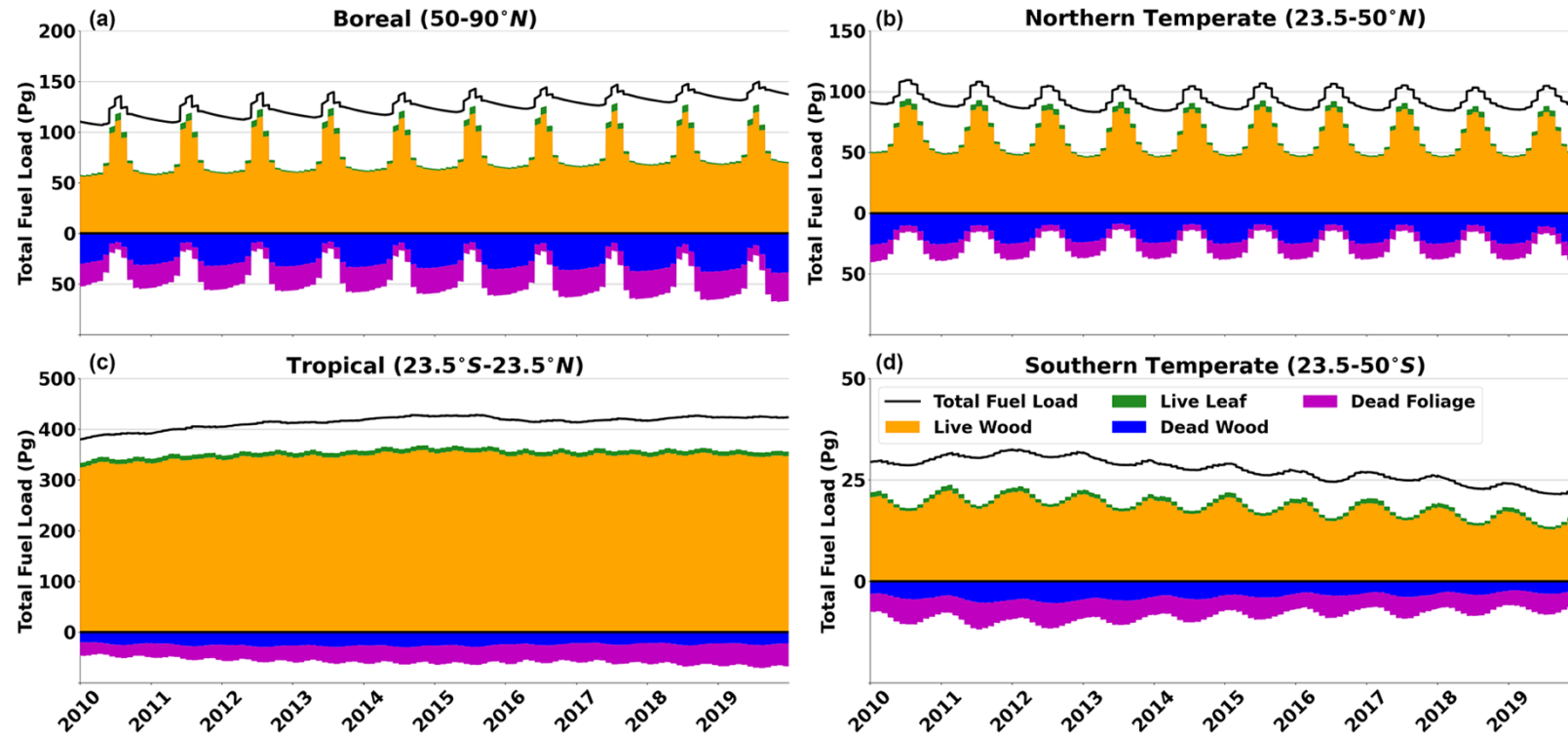
- High latitude deciduous leaf-on
- High latitude low litter
- Tropics little/no seasonality

- High latitude deciduous leaf-off
- Relatively smaller but detectable seasonality in high latitude live wood.
- High latitude high litter

DJF

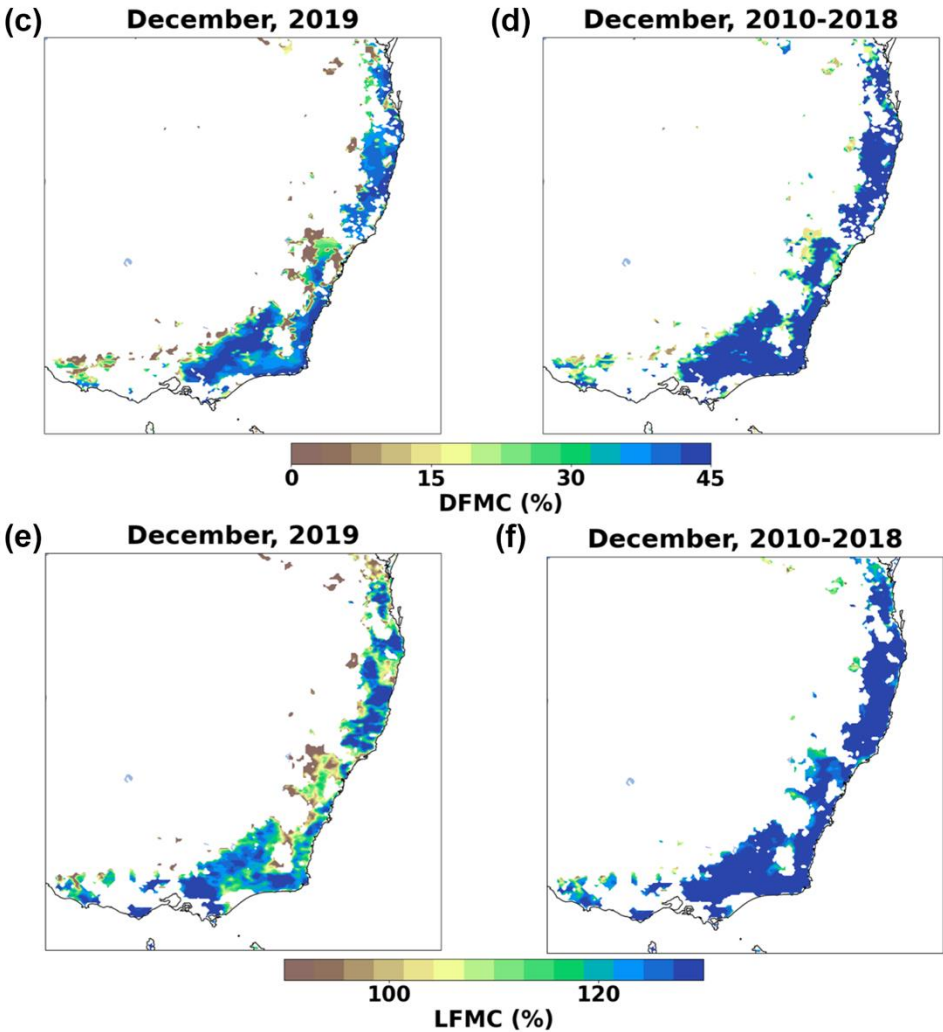
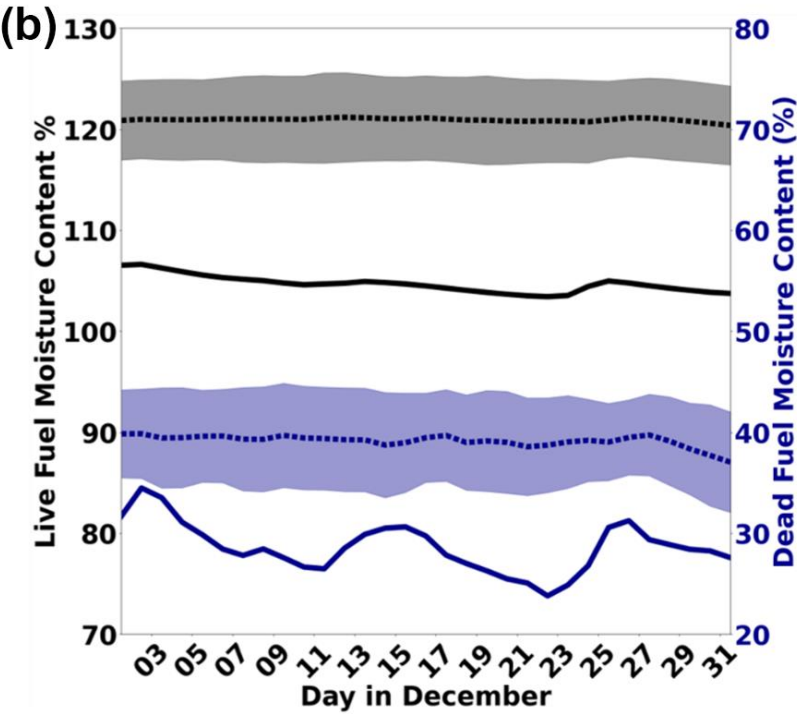
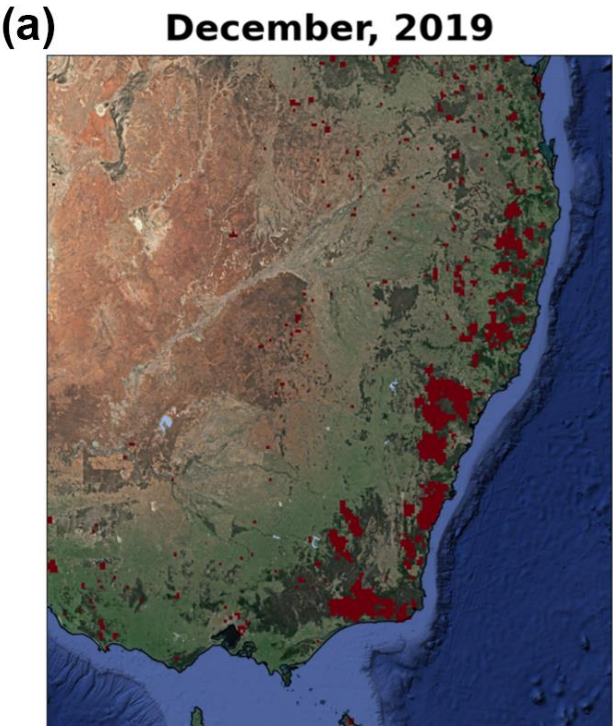


Sparky-Fuel



Region	Total fuel load (Pg)	Live foliage (Pg)	Live wood (Pg)	Dead foliage (Pg)	Dead wood (Pg)	Trend (2010–2019) (Pg yr ⁻¹)
Northern boreal (50–90° N)	126 ± 10	2.9 ± 2.0	76 ± 19	27 ± 9	21 ± 6	+2.6
Northern temperate (23.5–50° N)	93 ± 7	2.6 ± 1.5	61 ± 15	19 ± 6	10 ± 3	−0.2
Tropics (23.5° S to 23.5° N)	414 ± 11	9.0 ± 0.2	347 ± 7	25 ± 2	34 ± 6	+3.1
Southern temperate (50–23.5° S)	27 ± 3	0.9 ± 0.2	18 ± 2	3.7 ± 0.8	4.5 ± 0.7	−0.9
Global	661 ± 20	15 ± 3	502 ± 32	75 ± 14	69 ± 11	+4.5

Sparky-Fuel

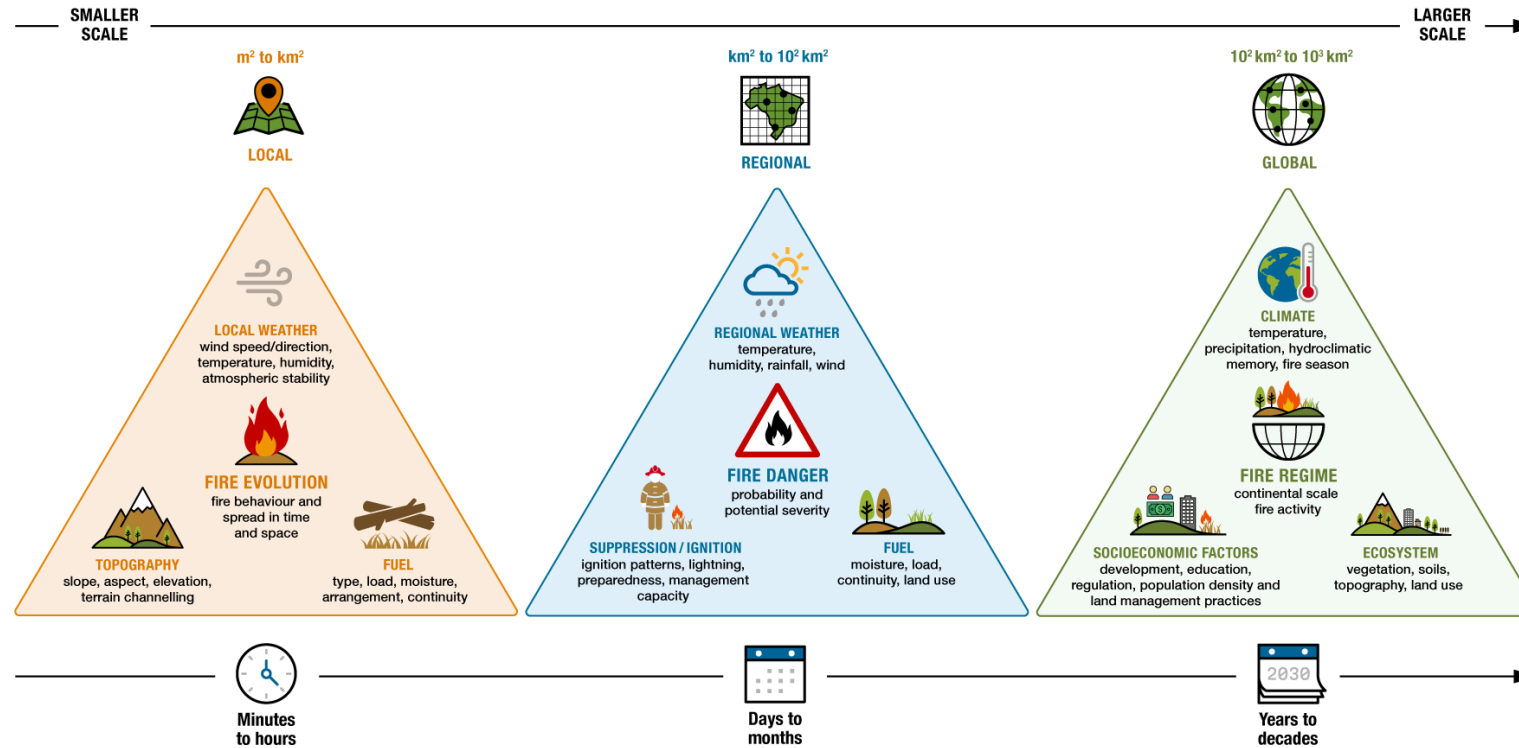


Sparky-Evolve (in development)



Event Scale

- Destruction of homes of homes and infrastructure
- Displacement of communities
- Loss of life and injury
- Local air quality impacts



Fire evolution modelling

High-cost physical rate-of-spread models, typically not viable in real-time.

Sparky-Evolve

Given a fire detection can we simulate evolution and disseminate that a timely manner for operations?

Potential observation platforms:
Sentinel-3, MTG, OroraTech, Firesat.

Currently MTG available at ~1km, ~20minutes behind real-time.

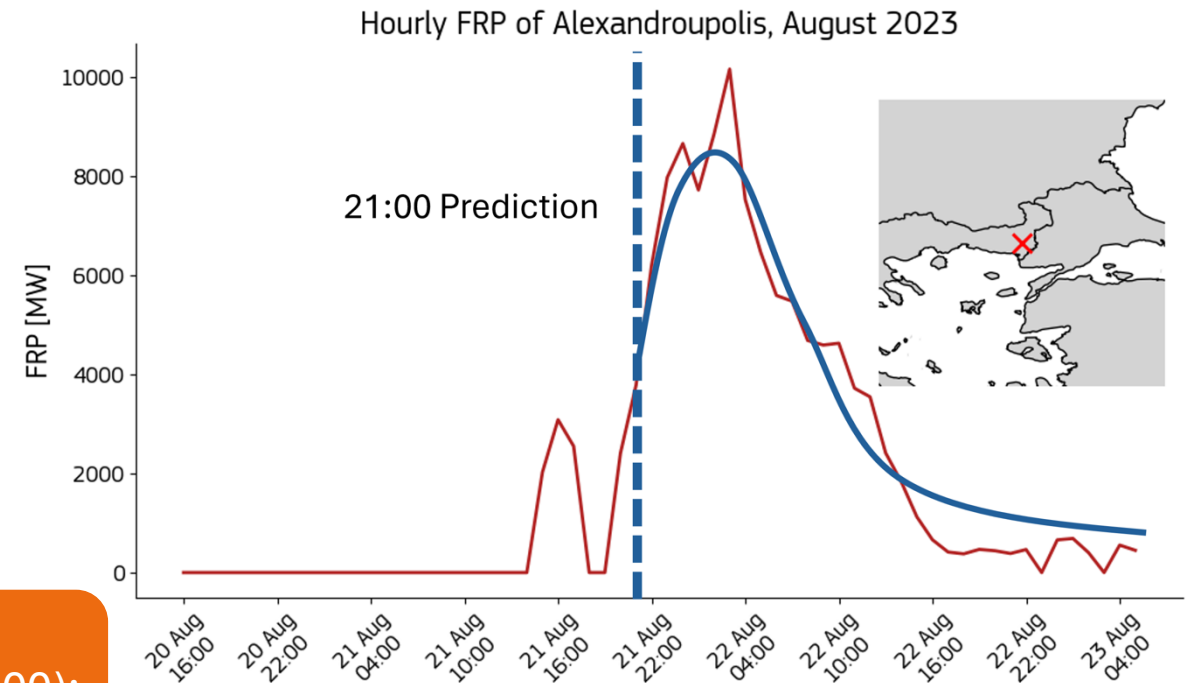
Retrieval:
21:00

Acquired and
Processed:
21:30

6-hour Forecast
Delivered (21:00-03:00):
21:40

Why?

- Provide real-time fire forecast for tactical fire management.
- Provide real-time fire radiative power as input to fire emission and air quality systems (GFAS in CAMS IFS-COMPO)

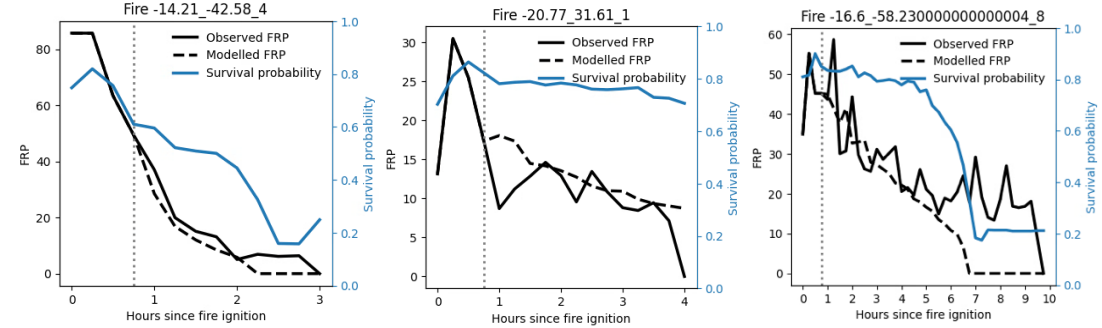


Sparky-Evolve

Retrieval:
21:00

Acquired and
Processed:
21:30

6-hour Forecast
Delivered (21:00-03:00):
21:40



Acquire latest NWP
forecast data
(hourly – 9km)

Use ancillary fuel
and socioeconomic
data (9km)

Fire Survival Model
(XGBoost – similar to PoF)

$P(f) < 0.5$

Fire Extinguished

$P(f) > 0.5$

Temporal Fusion
Transformer for FRP
evolution

McNorton *et al.*, in prep

Sparky-Danger (PoF / BA)

km² to 10² km²



REGIONAL



Regional Scale

- Air quality degradation (PM_{2.5}, PM₁₀, O₃, NO_x, etc.)
- Fire synchronicity for resource management
- Regional disruption through indirect impacts
- Agricultural disruption



Ecosystem Scale

- Loss of habitat and biodiversity
- Requirement for ecosystems (seedpods etc.)
- Promotes biodiversity
- Changes in vegetation, soil and moisture



FIRE DANGER
probability and potential severity



SUPPRESSION / IGNITION
ignition patterns, lightning, preparedness, management capacity



FUEL
moisture, load, continuity, land use



Fire danger forecasts

Fire Weather Index for fire severity based on 4 weather variables and no fuel and ignitions.



Seasonal forecasts

Seasonal FWI, only applicable as a weather-informed anomaly.



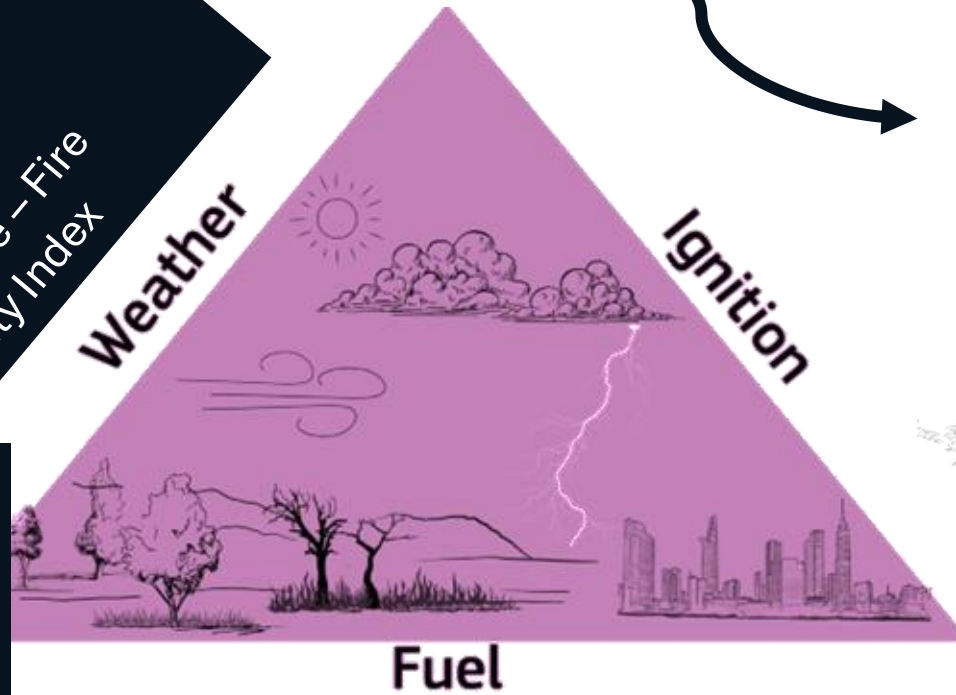
Days to months

Sparky-Danger

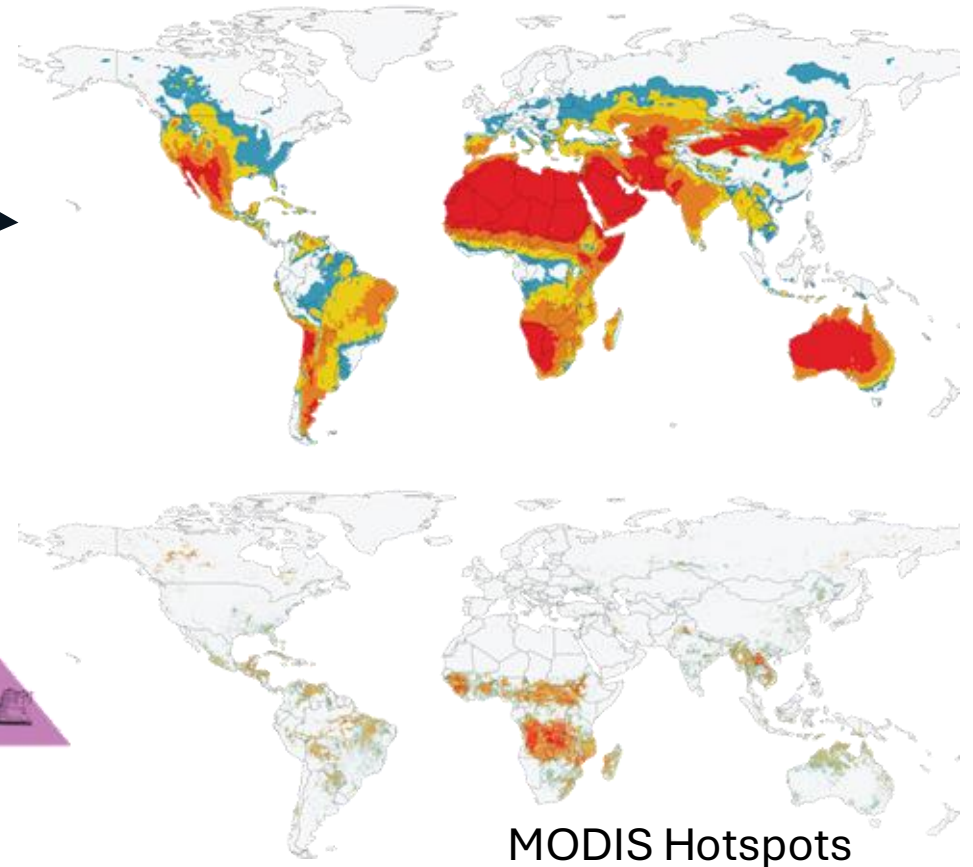
European GEFF – Fire
Weather Index
Met Office – Fire
Severity Index

USA – National Fire
Danger Rating System*

Australia– Australian Fire
Danger Rating System*



*Simplified static fuel type assumptions



Can we provide forecasts that predict the probability of a fire occurring?

Probability of Fire

Requirements to model fire danger:

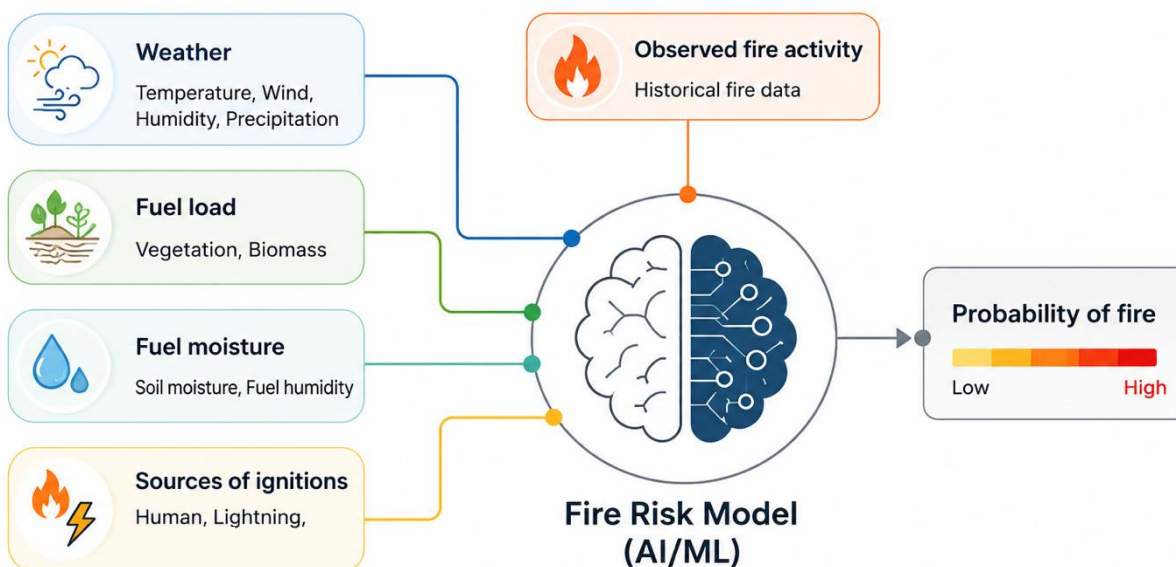
- ~~Data~~

- Physical Description Relating Data to Fire Behaviour
- Stochastic Nature of Fire Behaviour

Variable	Category	Frequency	Source	Forecast?
Precipitation	Weather	Daily	IFS	Y
2m Temperature	Weather	Daily	IFS	Y
2m Dewpoint Temperature	Weather	Daily	IFS	Y
10m Wind Speed	Weather	Daily	IFS	Y
Type of High Vegetation	Fuel/Ign	Yearly	IFS	N
Type of Low Vegetation	Fuel/Ign	Yearly	IFS	N
Urban Cover	Ignition	Static	IFS	N
Lightning Intensity	Ignition	Daily	IFS	Y
Population Density	Ignition	Static	GPW v4 – SEDAC	N
Total Road Length	Ignition	Static	Global Roads Inventory Dataset	N
Orography	-	Static	IFS	N

Variable	Category	Frequency	Source	Forecast?
Live Leaf Load	Fuel	Daily	IFS-Sparky	Y
Live Wood Load	Fuel	Daily	IFS-Sparky	Y
Dead Foliage Load	Fuel	Daily	IFS-Sparky	Y
Dead Wood Load	Fuel	Daily	IFS-Sparky	Y
Dead Foliage Moisture	Fuel	Daily	IFS-Sparky	Y
Dead Wood Moisture	Fuel	Daily	IFS-Sparky	Y
Live Fuel Moisture	Fuel	Daily	IFS-Sparky	Y
Low Vegetation LAI	Fuel	Monthly	ESA-CCI	N
High Vegetation LAI	Fuel	Monthly	ESA-CCI	N
High Vegetation Cover	Fuel	Yearly	IFS	N
Low Vegetation Cover	Fuel	Yearly	IFS	N

Completing the triangle distances us from physical understanding



SPARKY
THE ECMWF FIRE MODEL

- The **Global Probability of Fire (PoF)** has been running in real time at **ECMWF** since 2023.
- The model combines **numerical weather predictions**, **land surface models**, and **satellite observations**.
- PoF is based on an **Extreme Gradient Boosting (XGBoost)** algorithm using a **probabilistic classifier**.
- It is trained on active fire detections from **MODIS**, **VIIRS**, **GOES-E**, **Meteosat**, and **Himawari** satellites.
- The model produces a **daily 10-day forecast** at **9 km** and **1 km** resolution globally.

Geophysical Research Letters*

Research Letter | [Open Access](#) | [CC BY](#)

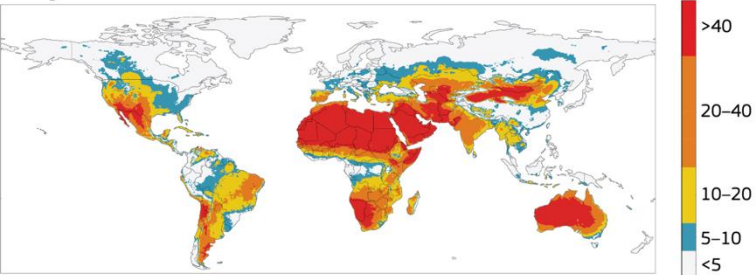
A Global Probability-Of-Fire (PoF) Forecast

[J. R. McNorton](#) [✉](#) [F. Di Giuseppe](#) [E. Pinnington](#) [M. Chantry](#) [C. Barnard](#)

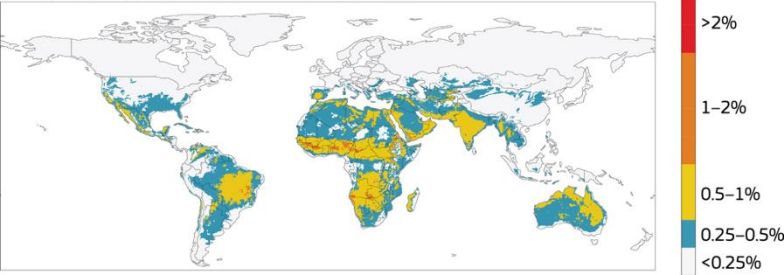
First published: 14 June 2024 | <https://doi.org/10.1029/2023GL107929> | [VIEW METRICS](#)

Why data matters

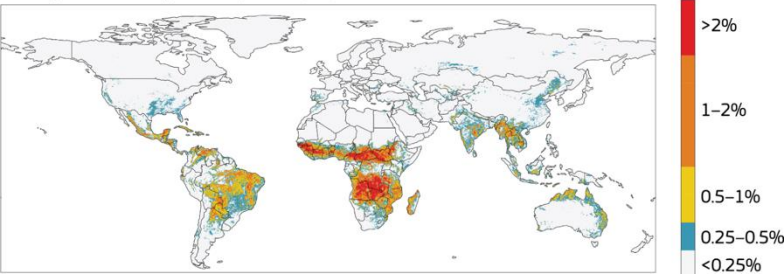
Average Fire Weather Index



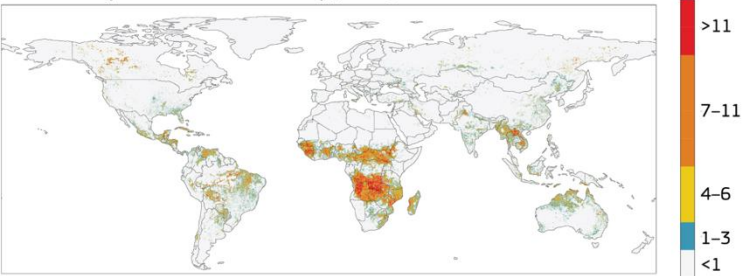
Average data-driven probability of fire (weather only)



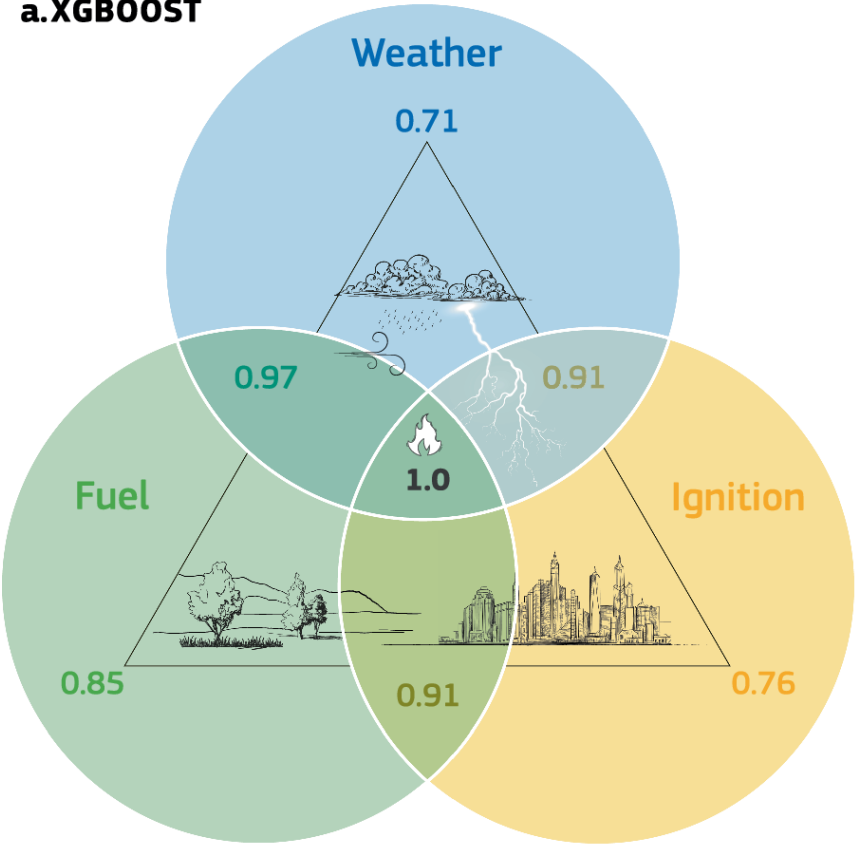
Average data-driven probability of fire (all)



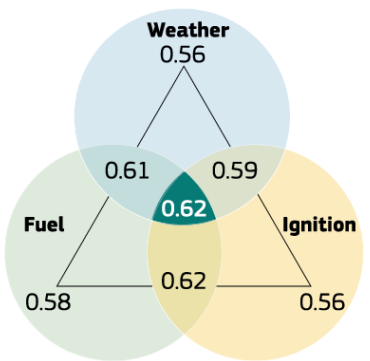
Number of days with recorded fire activity (MODIS)



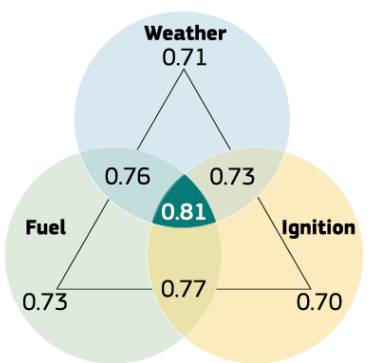
a. XGBOOST



b. Random forest



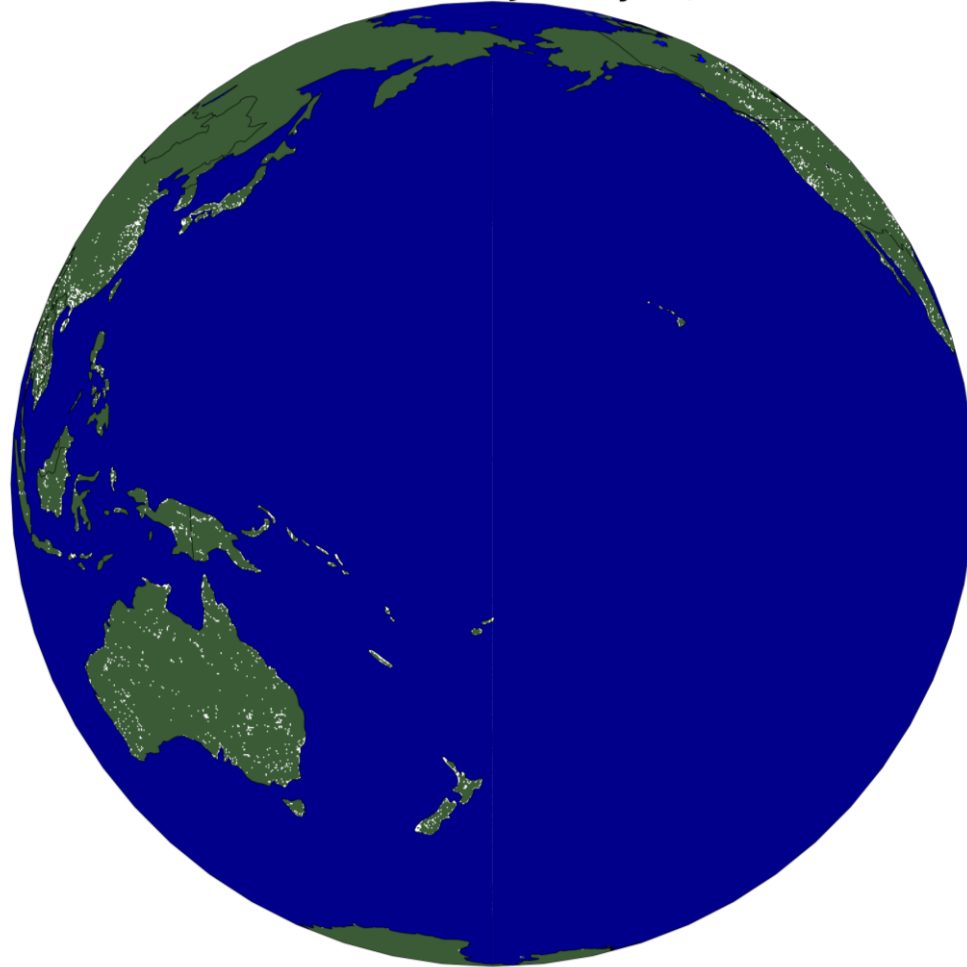
c. Neural Network



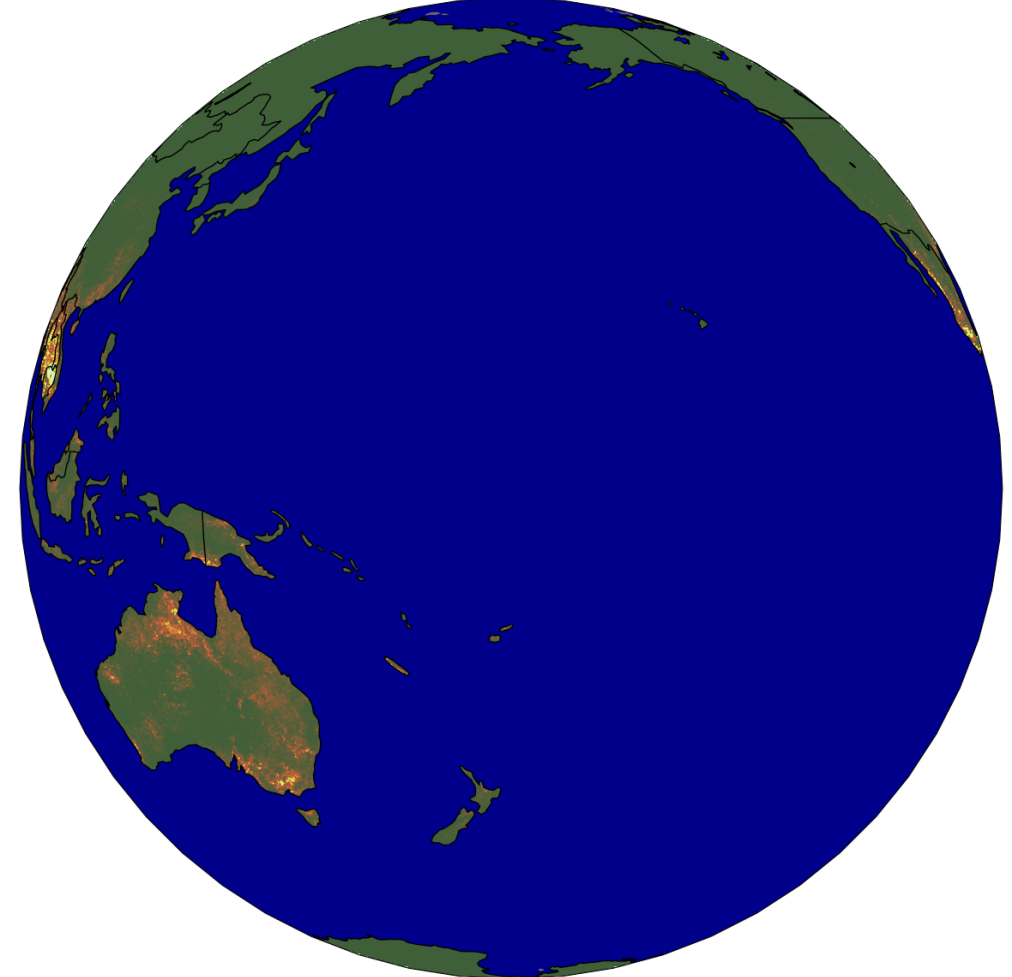
Article | [Open access](#) | Published: 01 April 2025
Global data-driven prediction of fire activity
[Francesca Di Giuseppe](#) [✉](#), [Joe McNorton](#) [✉](#), [Anna Lombardi](#) & [Fredrik Wetterhall](#)
[Nature Communications](#) **16**, Article number: 2918 (2025) | [Cite this article](#)
26k Accesses | 28 Citations | 90 Altmetric | [Metrics](#)

Probability of Fire

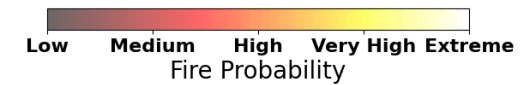
Observed Fires for January 01, 2024



Forecast for January 01, 2024

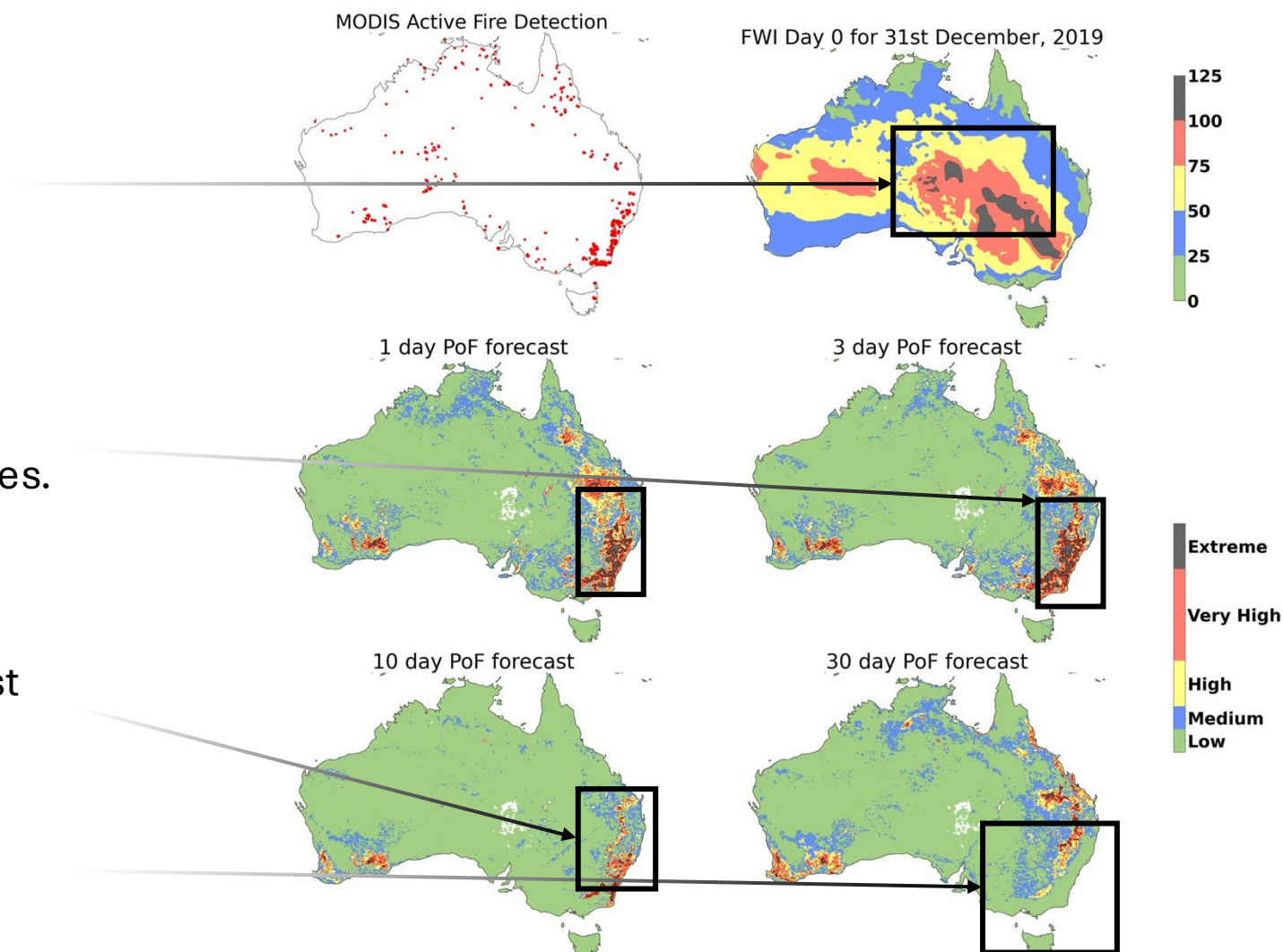


SPARKY
THE ECMWF FIRE MODEL



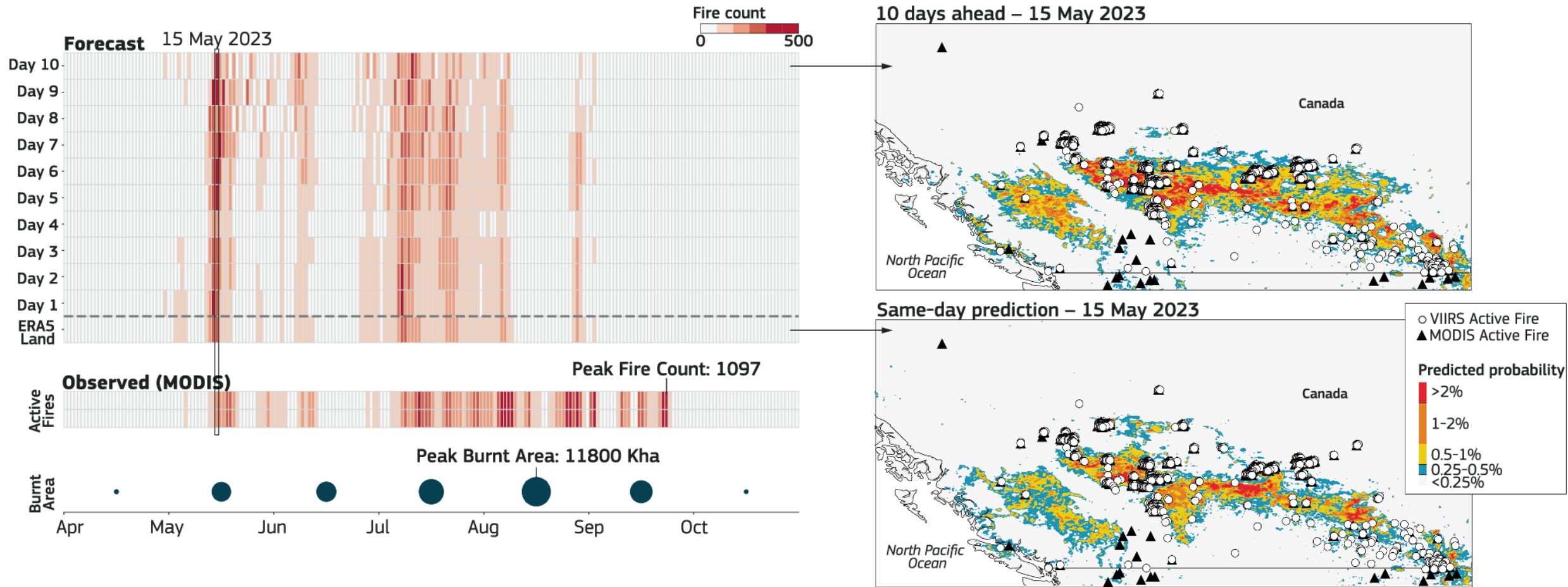
Probability of Fire

- Including fuel load removes high danger forecasts over fuel sparse regions.
- Representation of live fuel moisture better captures fire danger in regions with live fuel fires.
- Noticeable improvement in long range forecast skill.
- Accuracy of input data can still limit performance in some regions.



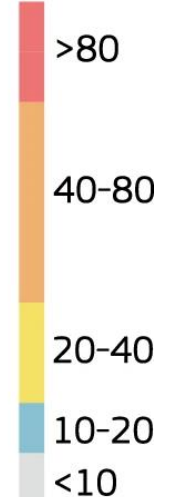
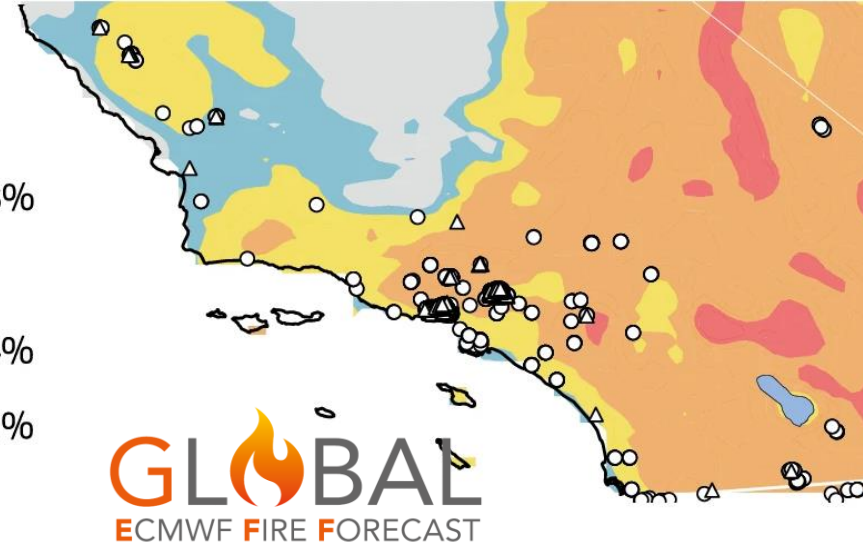
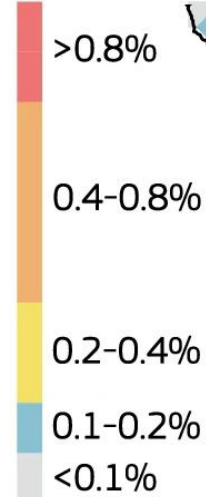
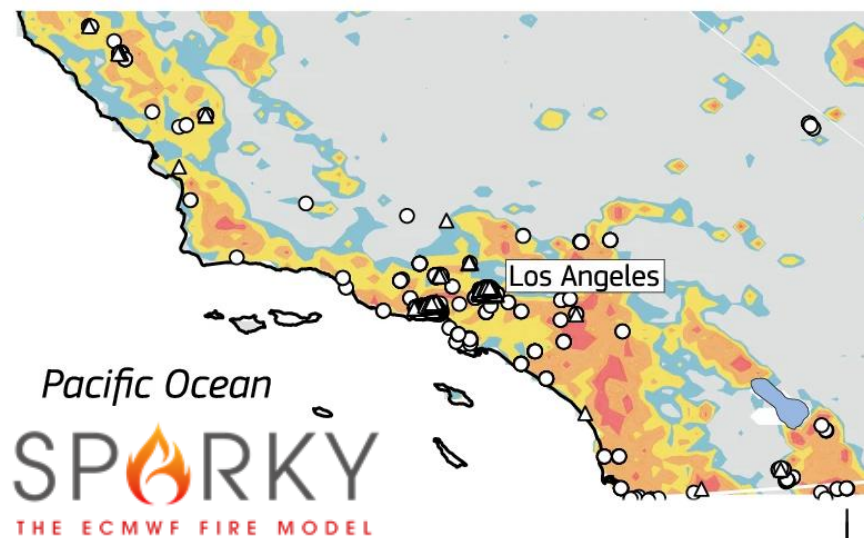
Probability of Fire

Prediction for the data-driven probability of fire over North-West Canada in 2023

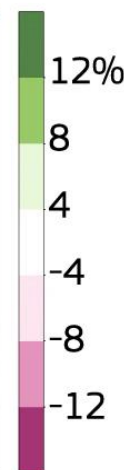
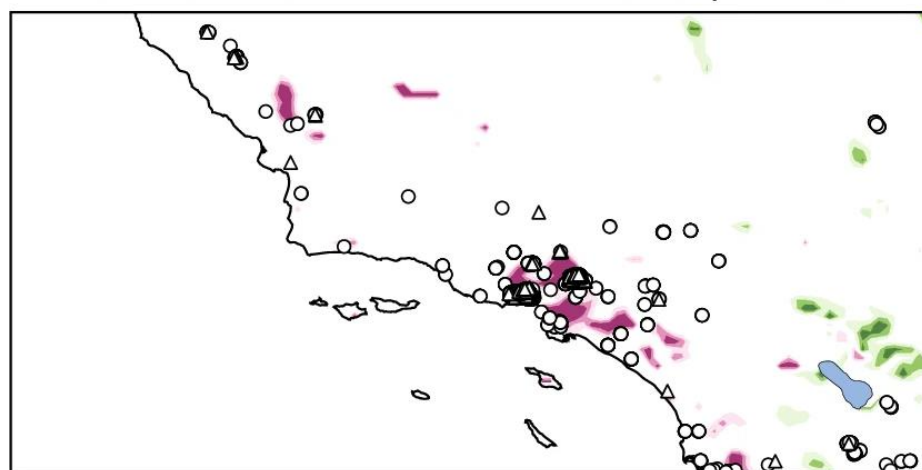


Probability of Fire

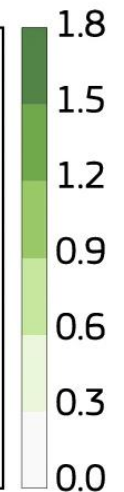
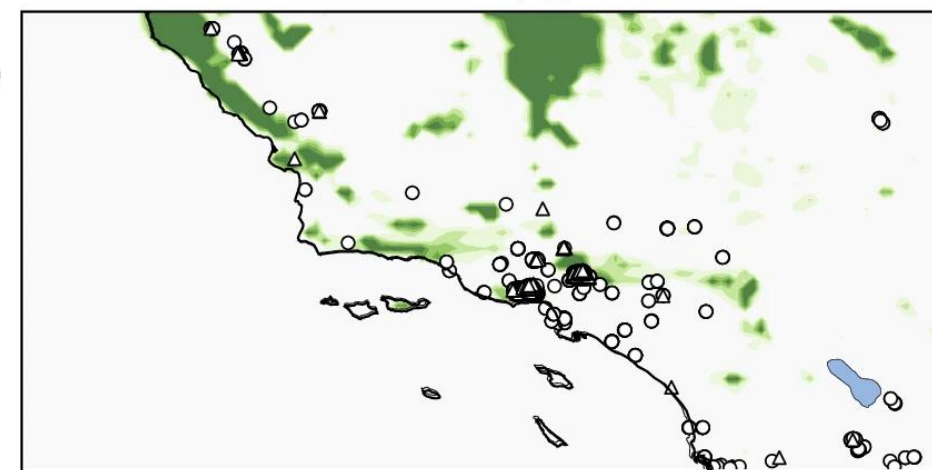
5-days Ahead



Dead Fuel Moisture Content Anomaly 7-1-2025

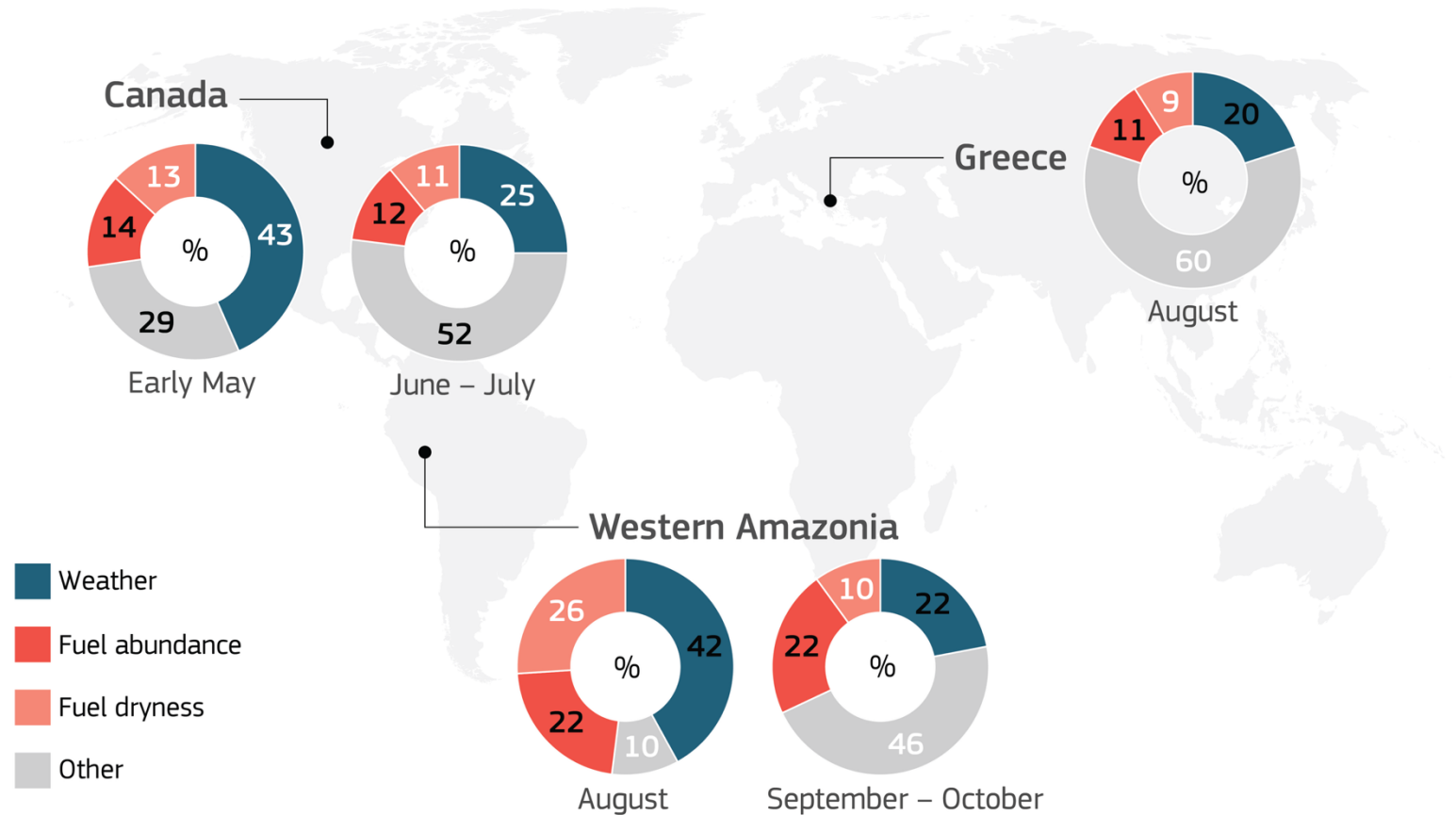


Total Fuel Load (kg m²) 7-1-2025



Probability of Fire – Use of SHAP Analysis

Main controls of fire activity 2023–2024

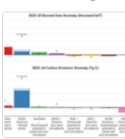


<https://doi.org/10.5194/essd-16-3601-2024>
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Review article |

State of Wildfires 2023–2024

Matthew W. Jones , Douglas I. Kelley , Chantelle A. Burton , Francesca Di Giuseppe , Maria Lucia F. Barbosa, Esther Brambleby, Andrew J. Hartley, Anna Lombardi, Guilherme Mataveli, Joe R. McNorton, Fiona R. Spuler, Jakob B. Wessel, John T. Abatzoglou, Liana O. Anderson, Niels Andela, Sally Archibald, Dolores Armenteras, Eleanor Burke, Rachel Carmenta, Emilio Chuvieco, Hamish Clarke, ...



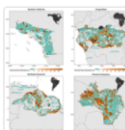
14 Aug 2024

<https://doi.org/10.5194/essd-17-5377-2025>
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Review article |

State of Wildfires 2024–2025

Douglas I. Kelley , Chantelle Burton , Francesca Di Giuseppe , Matthew W. Jones , Maria L. F. Barbosa, Esther Brambleby, Joe R. McNorton, Zhongwei Liu, Anna S. I. Bradley, Katie Blackford, Eleanor Burke, Andrew Clavarella, Enza Di Tomaso, Jonathan Eden, Igor José M. Ferreira, Lukas Fiedler, Andrew J. Hartley, Theodore R. Keeping, Sepp Lampe, Anna Lombardi, Guilherme Mataveli, Yuquan Qu, ...

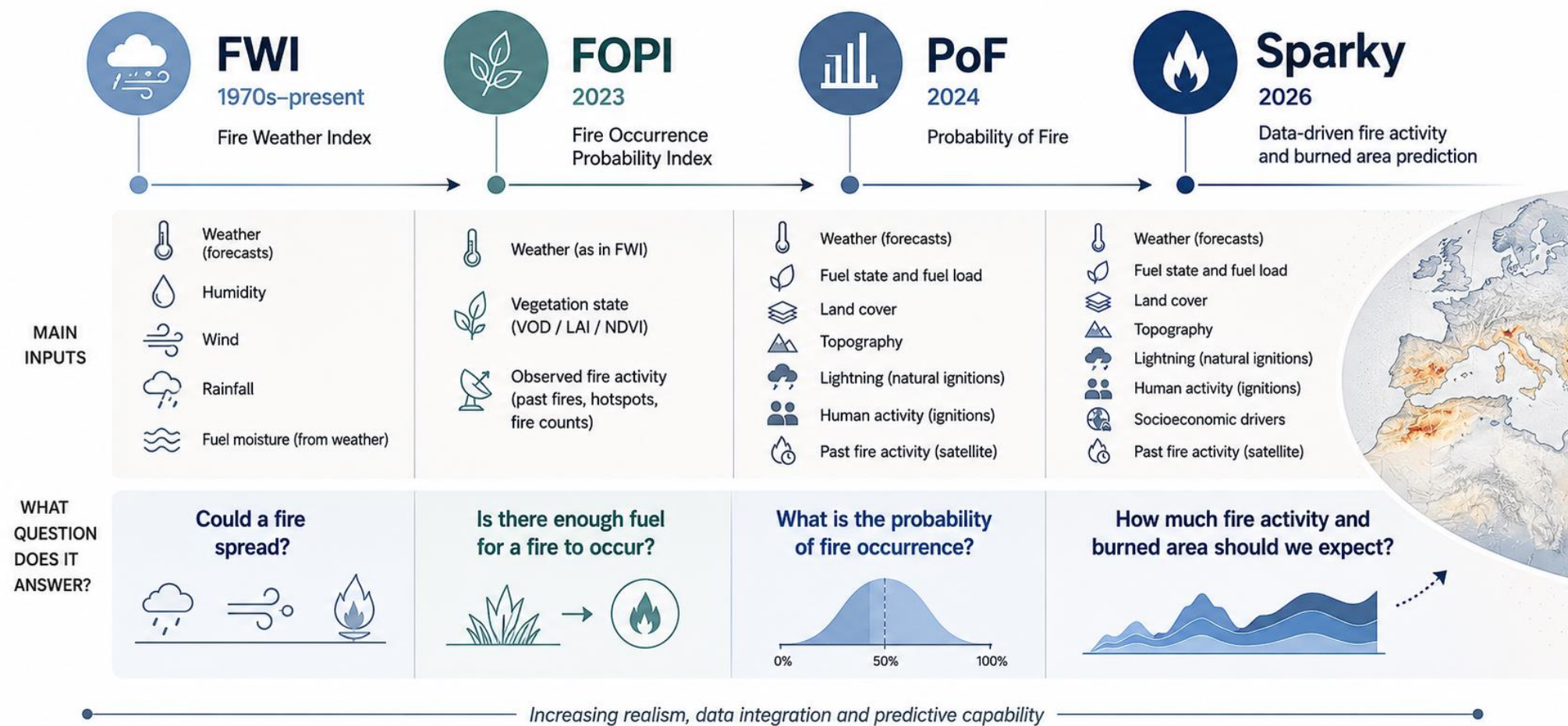


16 Oct 2025

Can we answer more than just where might fires occur?

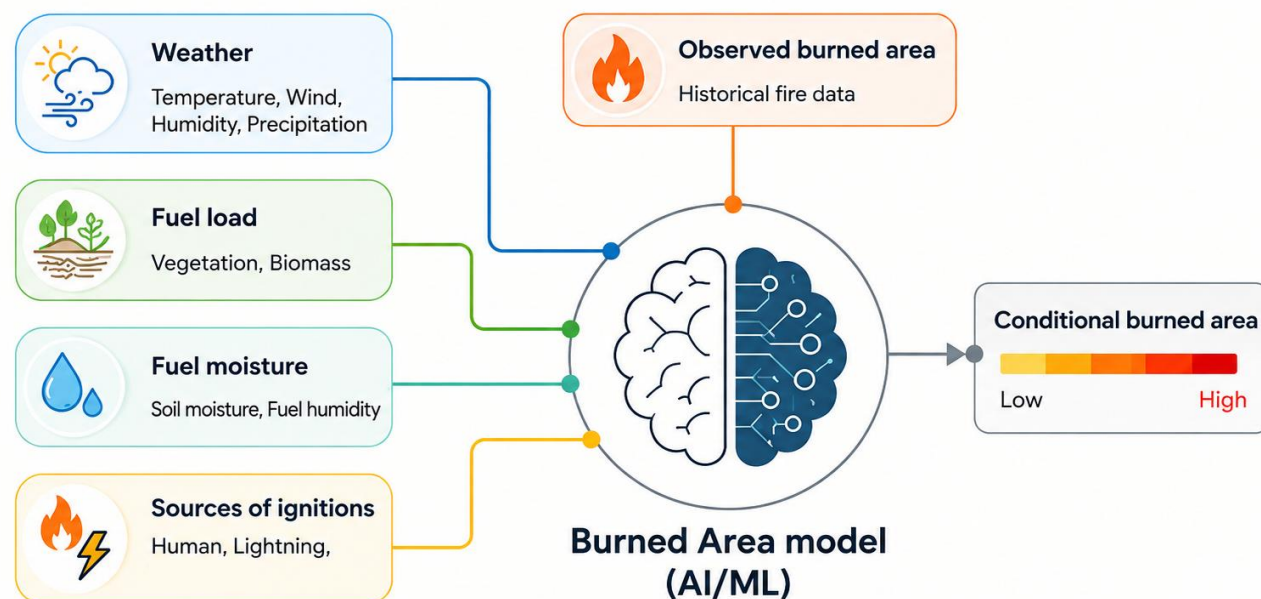
Evolution of ECMWF fire prediction systems

From weather-based fire danger to data-driven fire activity and burned area prediction



Sparky-Danger: The BA Model

- For strategic fire management where fires might occur is not enough.
- Can we say if a fire occurs how extreme is it likely to be and if so can we merge the two?

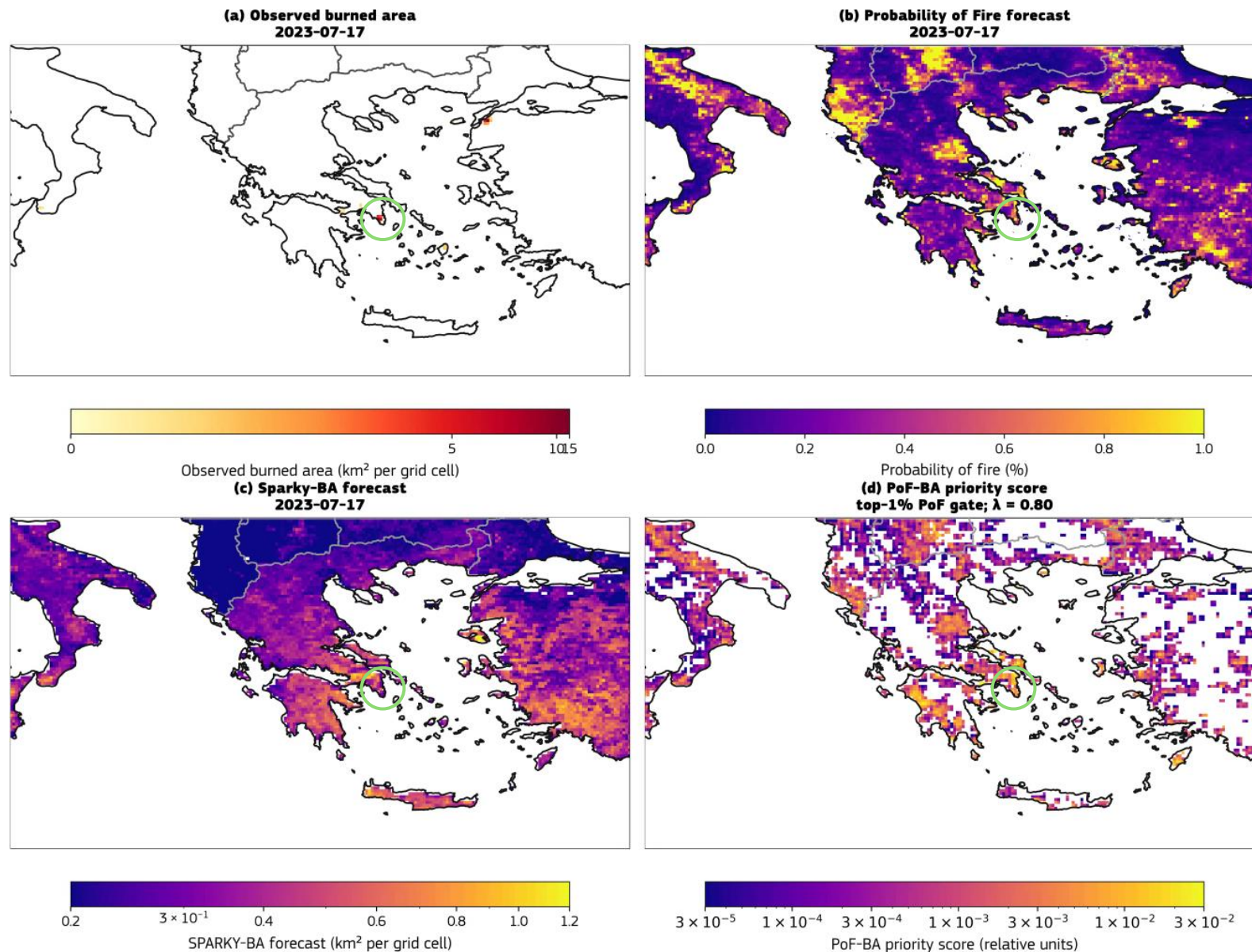


- The model combines **numerical weather predictions, land surface models, and satellite observations**.
- Sparky-BA is based on an **Extreme Gradient Boosting (XGBoost)** algorithm using a **regression algorithm**.
- It is trained on **MODIS Burned Area** making it conditional on fire occurrence.
- The model operates **daily** at **9km** resolution (not yet operational).

Sparky-Danger: In practice

- A combined metric to maximise capture based on capacity.

On-going work with paper in prep.

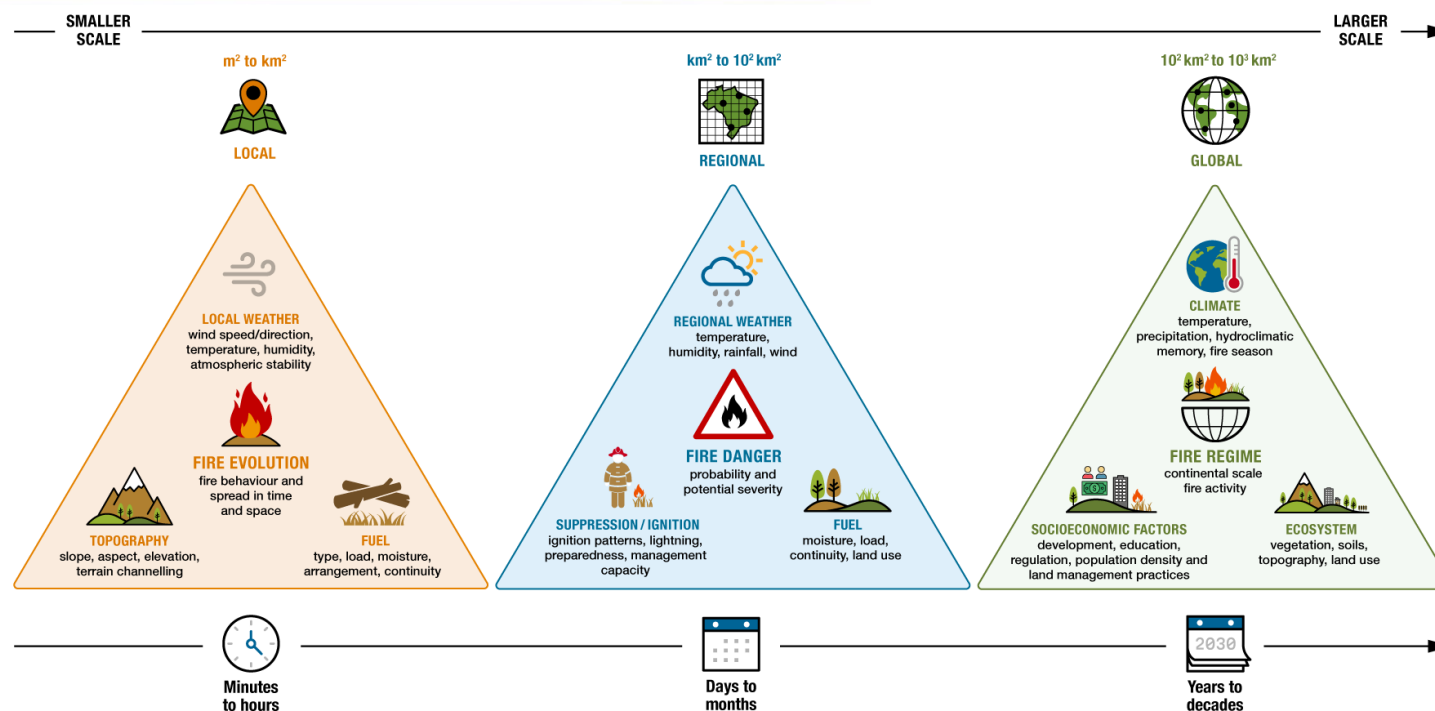


Sparky-Climate



Climate Scale

- Impact land use/management
- Changes in carbon storage and land-atmosphere exchange
- Shifts in fire regimes and extreme fire behaviour.

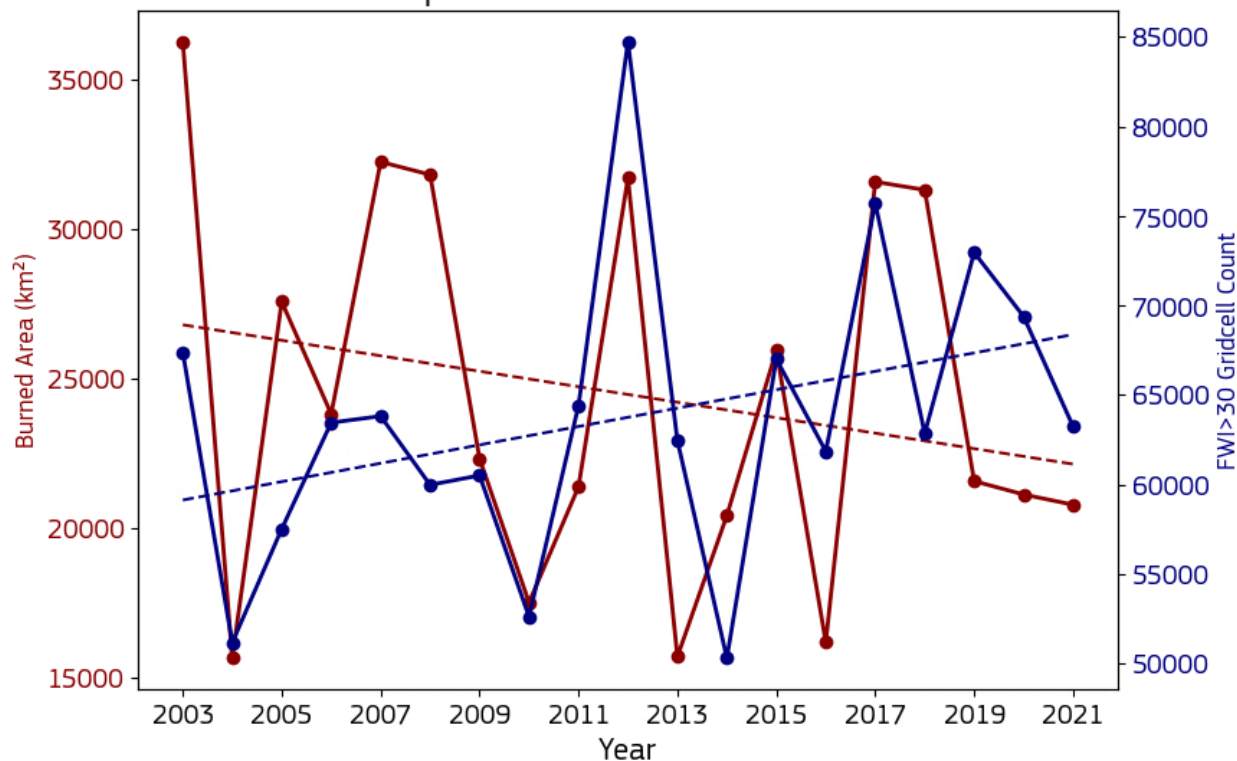


Climate projections
& reanalysis

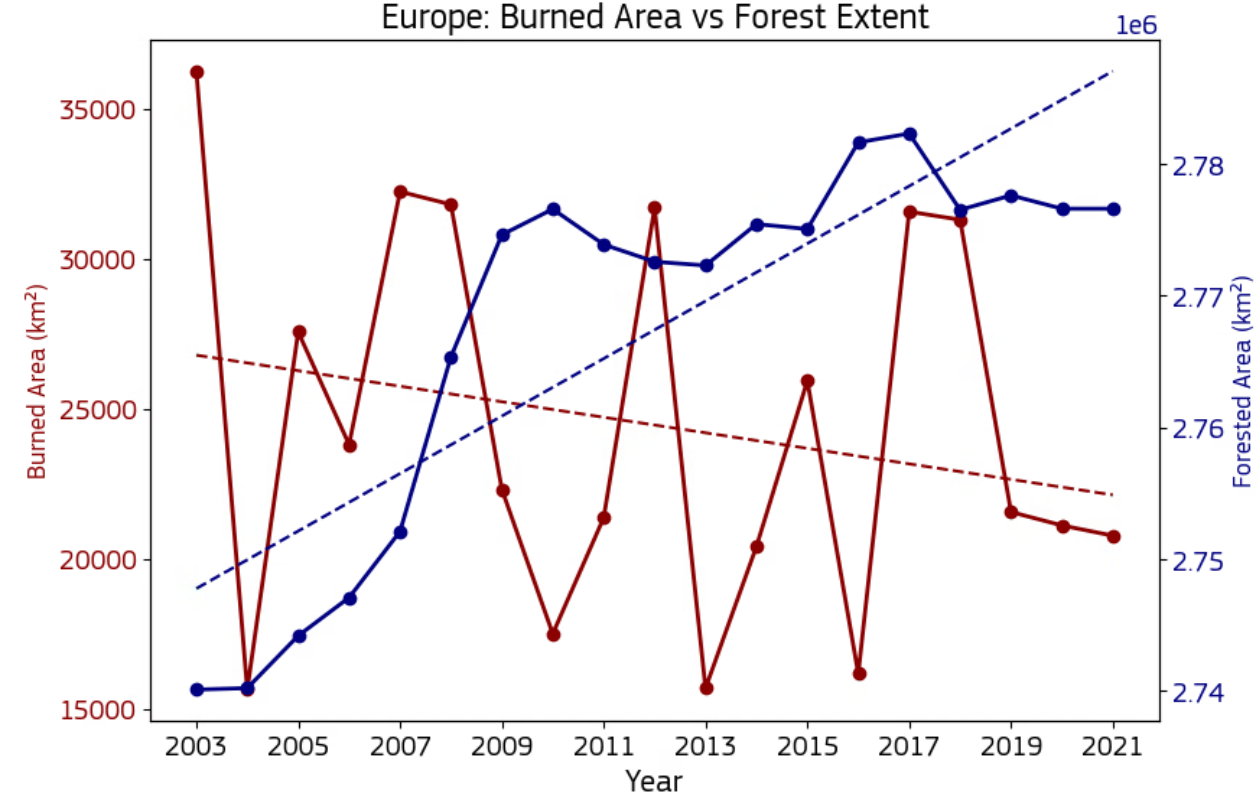
Fire-enable physical dynamic vegetation
models, which are not designed to capture
trends in fire behaviour.

FWI Trends $\neq$ Fire Trends

Europe: Burned Area vs Fire Weather



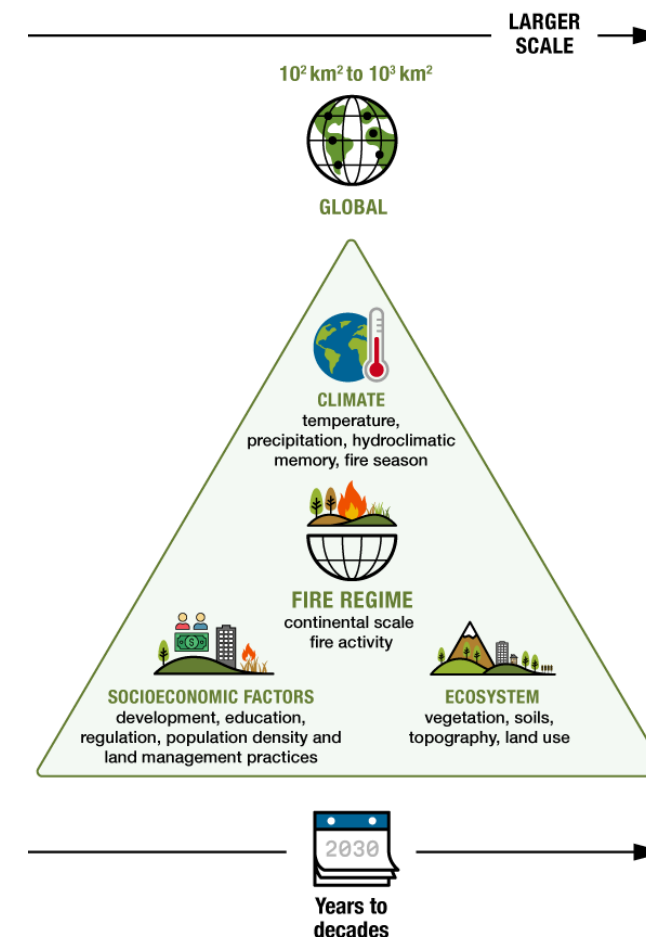
Europe: Burned Area vs Forest Extent



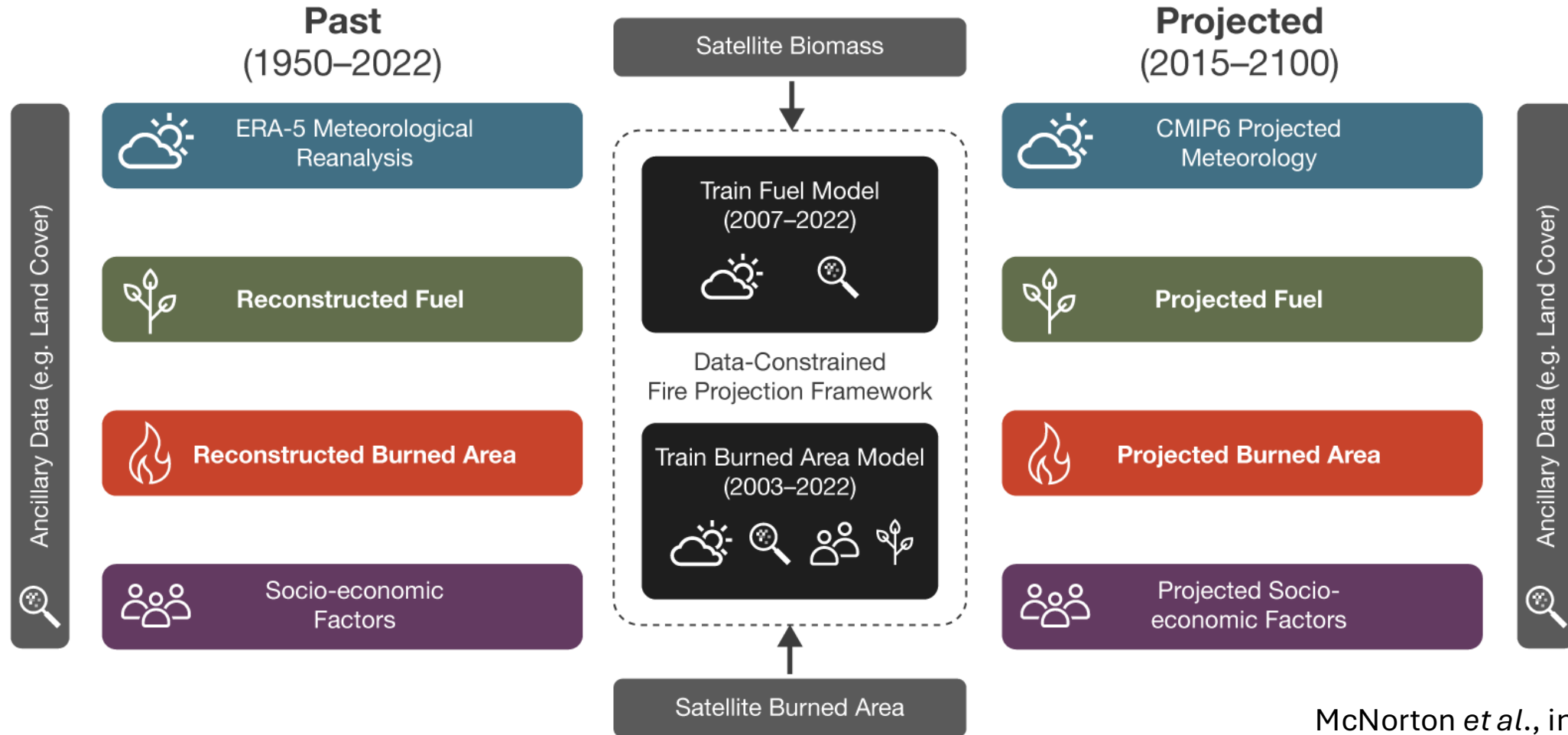
How Can We Model Stochastic Complex Fire Behaviour at Climate Timescales?

We cannot, at least not with that level of detail, but we can capture regime behaviour and trends...

- DGVMs are typically not designed to capture trends in burned area and they can be computational expensive at the climate timescale.
- Can we emulate the DGVM but also capture the trends by using all components of the fire regime triangle?



Sparky-Climate



McNorton *et al.*, in review

<https://xds.ecmwf.int/datasets/projections-fire-fuel-burned-area>

CMIP Models Considered

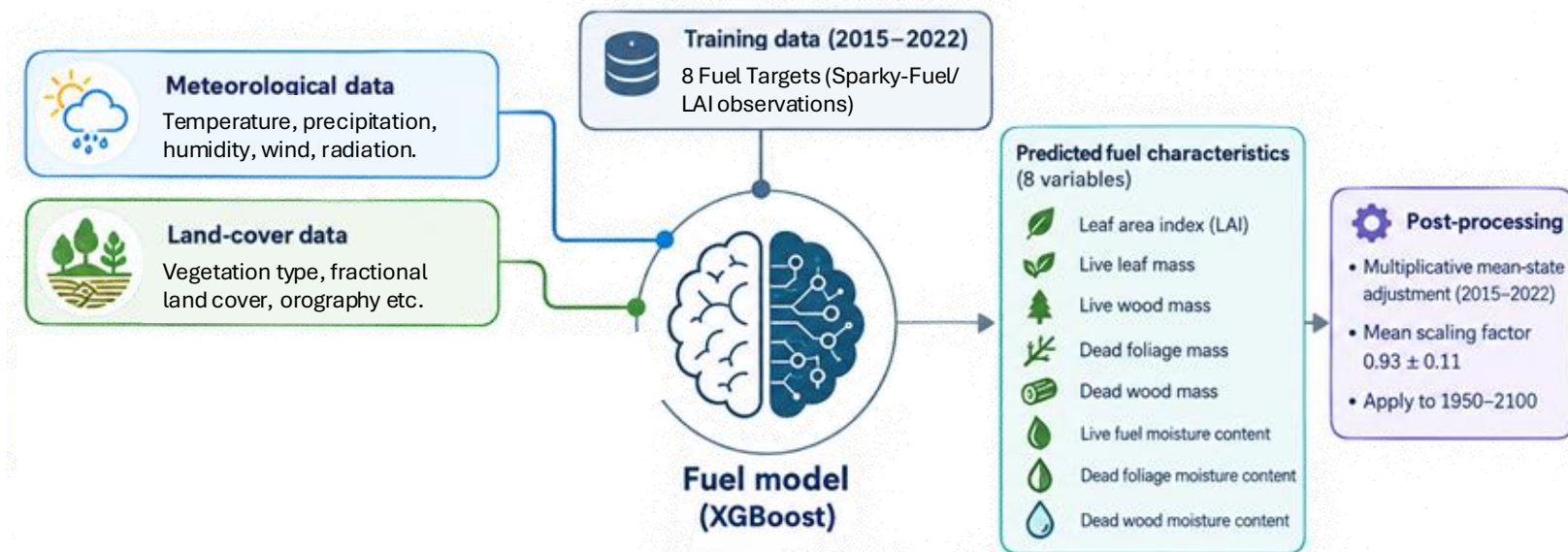
Scenario	SSP family	Narrative	Radiative forcing (W/m ²)	Approx. global warming by 2100 (°C)	Description
SSP1-1.9	SSP1 - Sustainability	Taking the Green Road	1.9	~1.5	Very low emissions; consistent with the Paris Agreement 1.5 °C target
SSP1-2.6	SSP1 — Sustainability	Taking the Green Road	2.6	~1.8	Low emissions; strong mitigation and sustainable development
SSP2-4.5	SSP2 — Middle of the Road	Middle of the Road	4.5	~2.7	Intermediate emissions; social and economic trends broadly follow historical patterns
SSP3-7.0	SSP3 — Regional Rivalry	A Rocky Road	7.0	~3.6	Medium-high emissions; regional rivalry, no additional climate policy
SSP4-3.4	SSP4 — Inequality	A Road Divided	3.4	~2.4	Low-to-intermediate emissions within a world of high inequality
SSP5-8.5	SSP5 — Fossil-fueled Development	Taking the Highway	8.5	~4.4	Very high emissions; fossil-fueled development with no additional climate policy

Model	Scenario Considered
ACCESS-CM2	SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5
CanESM5-CanOE	SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5
CMCC-CM2-SR5	SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5
CMCC-ESM2	SSP1-2.6, SSP2-4.5, SSP5-8.5
CNRM-CM6-1-HR	SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5
CNRM-ESM2-1	SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP4-3.4, SSP5-8.5
E3SM-1-1	SSP5-8.5
EC-Earth3-CC	SSP2-4.5, SSP5-8.5
KACE-1-0-G	SSP2-4.5, SSP3-7.0, SSP5-8.5
MIROC6	SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP4-3.4, SSP5-8.5
MIROC-ES2L	SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5
MPI-ESM1-2-LR	SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5
MRI-ESM2-0	SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP4-3.4, SSP5-8.5
NorESM2-MM	SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5
UKESM1-0-LL	SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP4-3.4, SSP5-8.5

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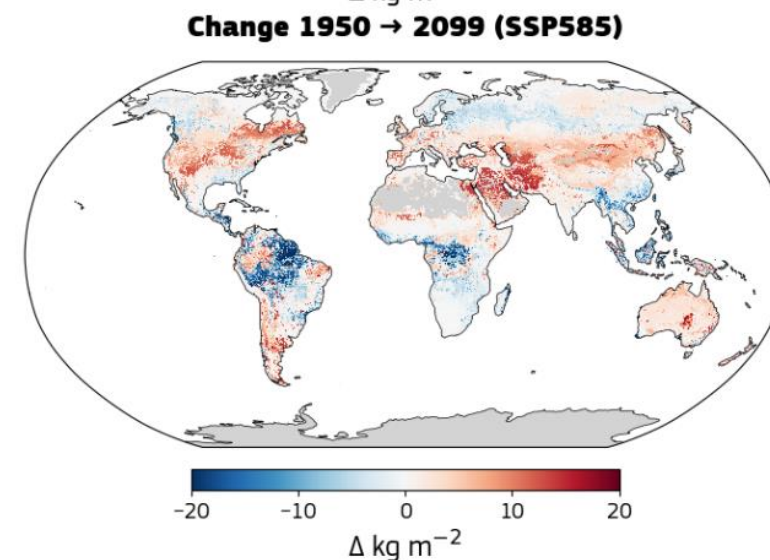
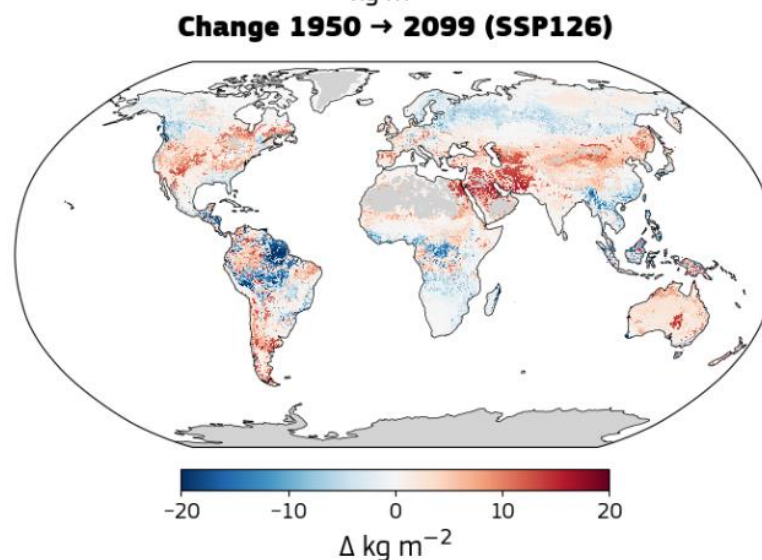
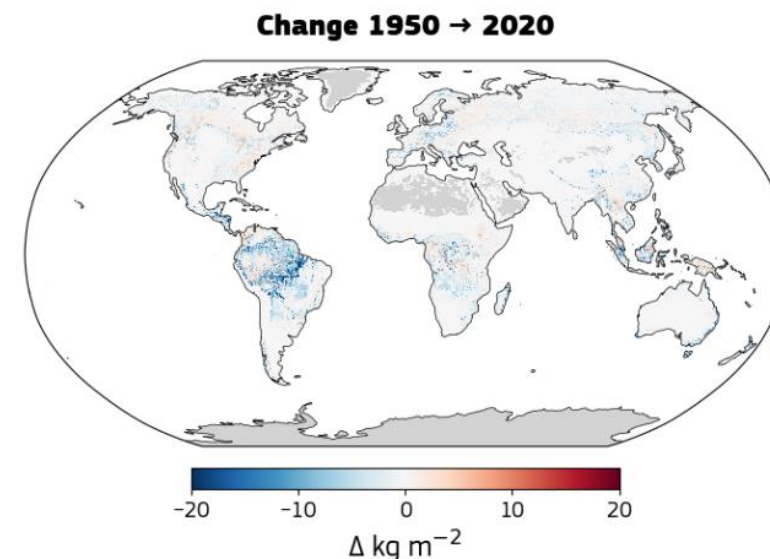
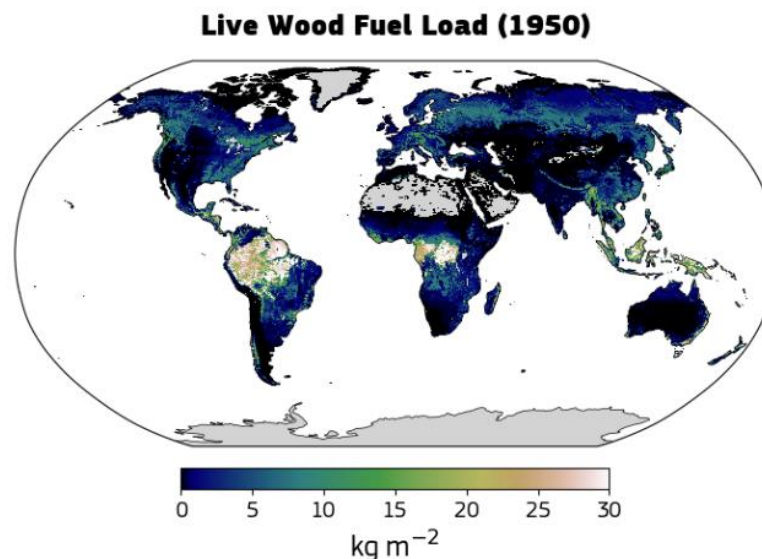
Representing Sparky-Fuel

- Sparky-Fuel, a physically constrained fuel dataset (anchored to ESA-CCI Biomass), is used to train a historic, and projected autoregressive fuel component of Sparky-Climate.
- Sparky-Climate (fuel) is based on an **Extreme Gradient Boosting (XGBoost)** algorithm using a **regression algorithm**.



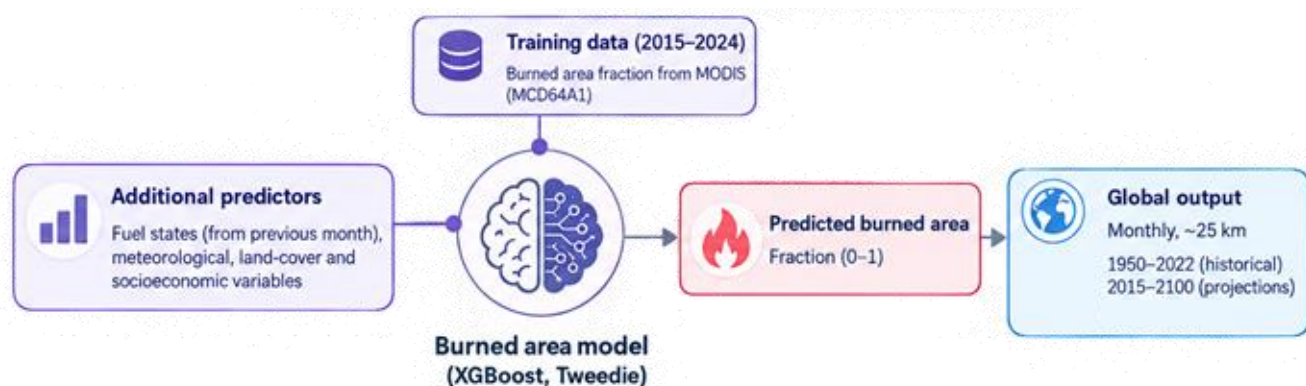
Representing Sparky-Fuel

- Model captures long-term declines in tropical forest biomass stocks since the 1950s.
- Projected model trends to 2100 are simulated under multiple SSP.



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Sparky-Climate (Burned Area)



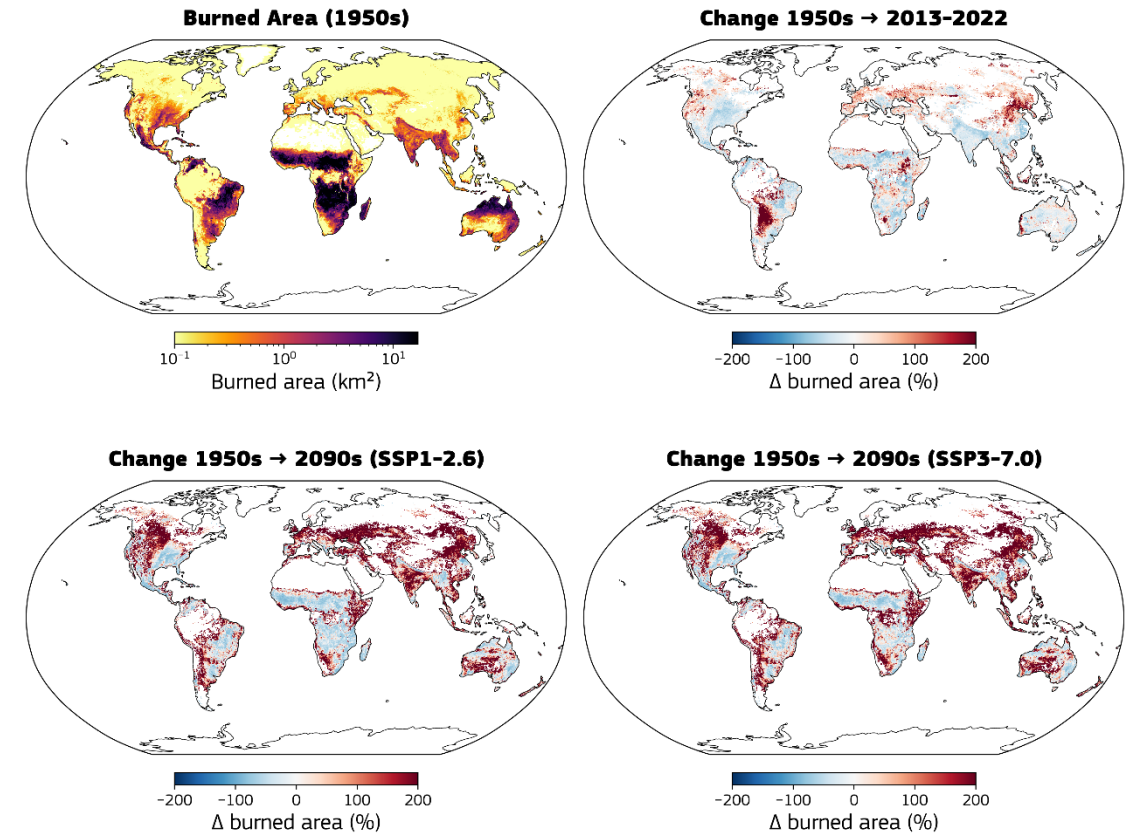
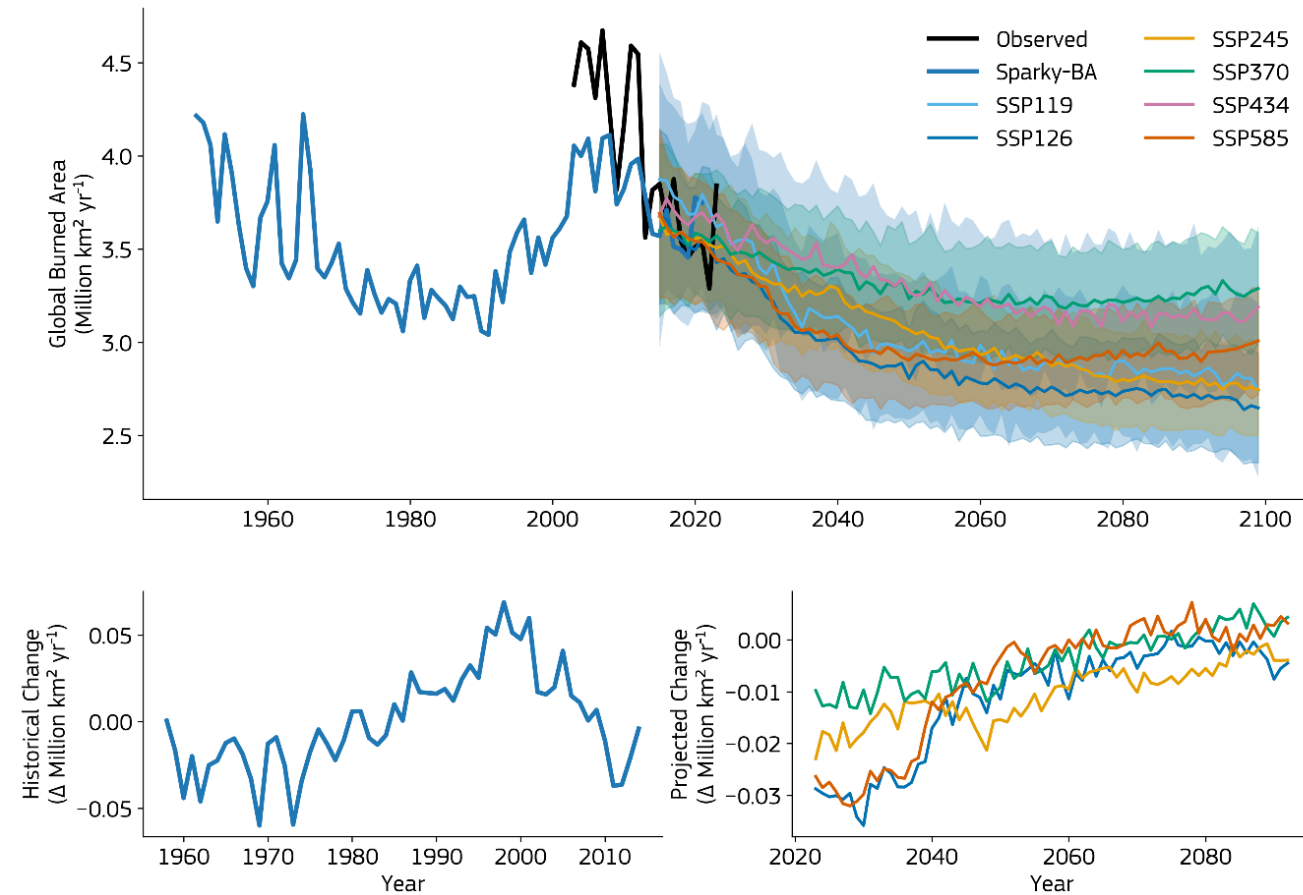
- The model combines reanalysis and projected meteorological forcing, emulated fuel characteristics, SSP-specific land use and socioeconomic factors.
- Sparky-Climate is based on an **Extreme Gradient Boosting (XGBoost)** algorithm using a **regression algorithm**.
- It is trained on **MODIS Burned Area Fraction** but is not conditional.
- The model operates **monthly** at **25km** resolution.

Sparky-Climate Input

Variable	Model	Historic Source	Reference	Projecte d	Source
High Vegetation Cover	Fuel, Burned Area	CERISE	(Tourigny et al., 2025)	LUH2	(Hurtt et al., 2020)
Low Vegetation Cover	Fuel, Burned Area	CERISE	(Tourigny et al., 2025)	LUH2	(Hurtt et al., 2020)
Type of High Vegetation	Fuel, Burned Area	CERISE	(Tourigny et al., 2025)	LUH2	(Hurtt et al., 2020)
Type of Low Vegetation	Fuel, Burned Area	CERISE	(Tourigny et al., 2025)	LUH2	(Hurtt et al., 2020)
High Vegetation LAI	Fuel*, Burned Area	Modelled	This study	Modelled	This study
Low Vegetation LAI	Fuel*, Burned Area	Modelled	This study	Modelled	This study
Dead Foliage Load	Fuel*, Burned Area	Modelled	This study	Modelled	This study
Dead Wood Load	Fuel*, Burned Area	Modelled	This study	Modelled	This study
Live Leaf Load	Fuel*, Burned Area	Modelled	This study	Modelled	This study
Live Wood Load	Fuel*, Burned Area	Modelled	This study	Modelled	This study
Dead Foliage Moisture	Fuel*, Burned Area	Modelled	This study	Modelled	This study
Dead Wood Moisture	Fuel*, Burned Area	Sparky-Fuel	This study	Modelled	This study
Live Fuel Moisture	Fuel*, Burned Area	Sparky-Fuel	This study	Modelled	This study
Soil Moisture	Fuel, Burned Area	ERA5	(Hersbach et al., 2020)	CMIP6	(Eyring et al., 2016)
2m Temperature	Fuel, Burned Area	ERA5	(Hersbach et al., 2020)	CMIP6	(Eyring et al., 2016)
Shortwave Radiation	Fuel, Burned Area	ERA5	(Hersbach et al., 2020)	CMIP6	(Eyring et al., 2016)
Wind Speed	Fuel, Burned Area	ERA5	(Hersbach et al., 2020)	CMIP6	(Eyring et al., 2016)
Relative Humidity	Fuel, Burned Area	ERA5	(Hersbach et al., 2020)	CMIP6	(Eyring et al., 2016)
Surface Pressure	Fuel, Burned Area	ERA5	(Hersbach et al., 2020)	CMIP6	(Eyring et al., 2016)
Total Precipitation	Fuel, Burned Area	ERA5	(Hersbach et al., 2020)	CMIP6	(Eyring et al., 2016)
Precipitation 5 th Percentile	Fuel, Burned Area	ERA5	(Hersbach et al., 2020)	ERA5	(Hersbach et al., 2020)
Precipitation 95 th Percentile	Fuel, Burned Area	ERA5	(Hersbach et al., 2020)	ERA5	(Hersbach et al., 2020)
Temperature 5 th Percentile	Fuel, Burned Area	ERA5	(Hersbach et al., 2020)	ERA5	(Hersbach et al., 2020)
Temperature 95 th Percentile	Fuel, Burned Area	ERA5	(Hersbach et al., 2020)	ERA5	(Hersbach et al., 2020)
Month	Fuel	-	-	-	-
Latitude	Fuel	-	-	-	-
Longitude	Fuel	-	-	-	-
Orography	Burned Area	ECLand	(Boussetta et al., 2021)	ECLand	(Boussetta et al., 2021)
Population Density	Burned Area	Reported/Modelled	(Zhuang et al., 2024)	Modelled	(Zhuang et al., 2024)
Gross Domestic Product	Burned Area	Reported/Modelled	(Feenstra et al., 2015; Kummu et al., 2025)	Modelled	(Wang and Sun, 2022)
Human Development Index	Burned Area	Reported/Modelled	(Liu et al., 2024)	Modelled	(Liu et al., 2024)
Road Density	Burned Area	Modelled	(Meijer et al., 2018)	Modelled	This study

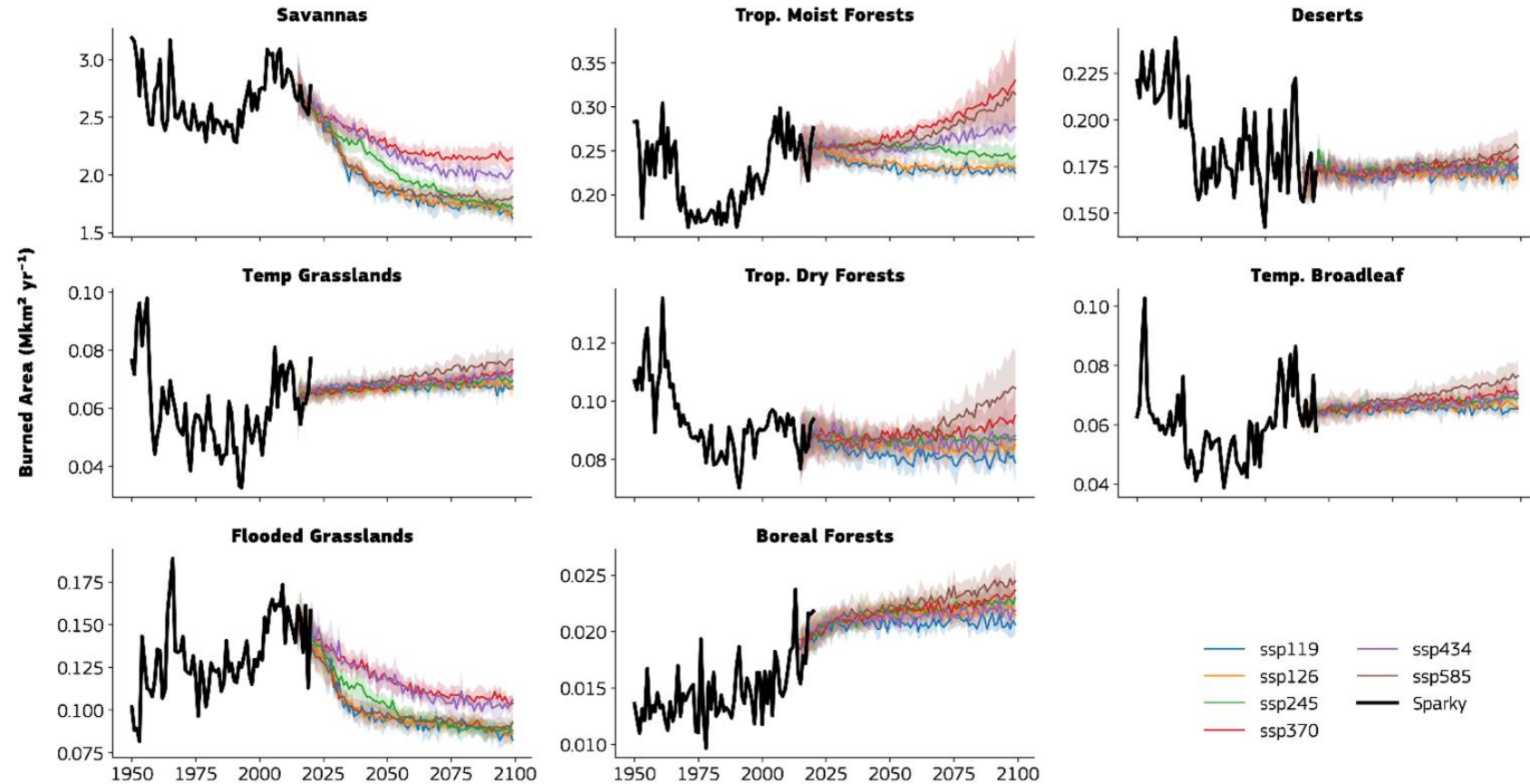
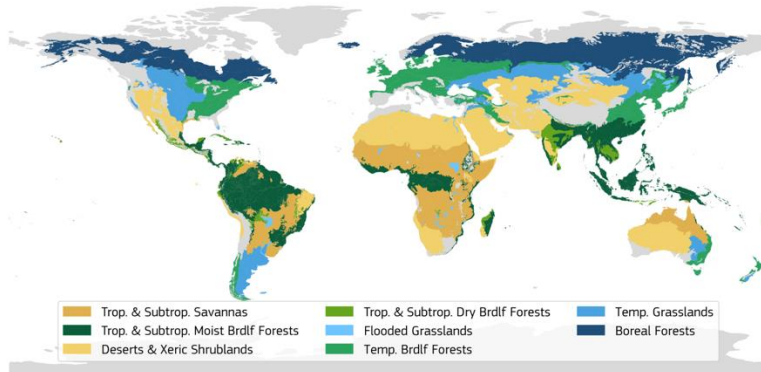
McNorton *et al.*, in review

Sparky-Climate Projections



McNorton *et al.*, in review

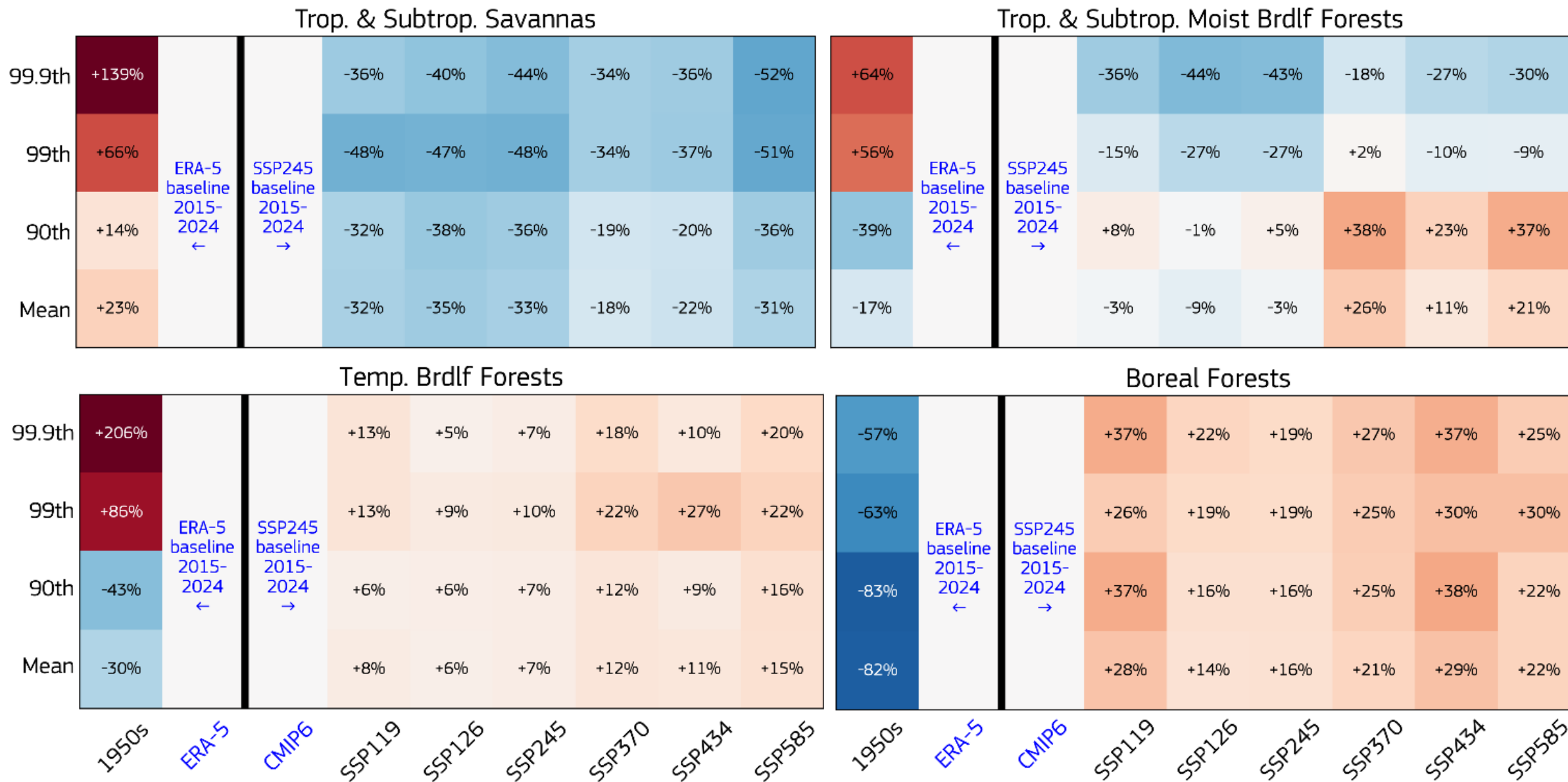
Burned Area Trends Differ by Biome



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Trends in Extremes Differ By Biome

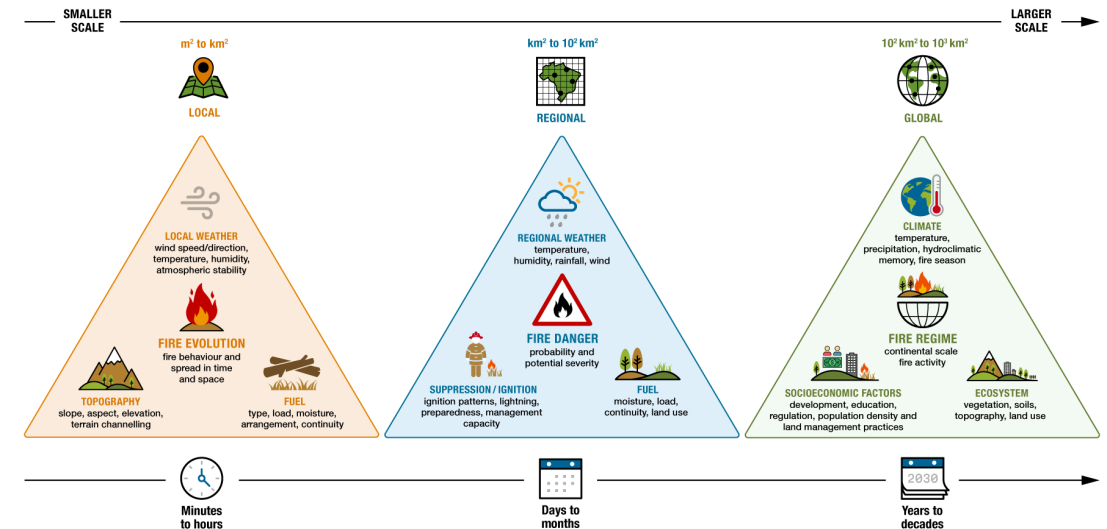
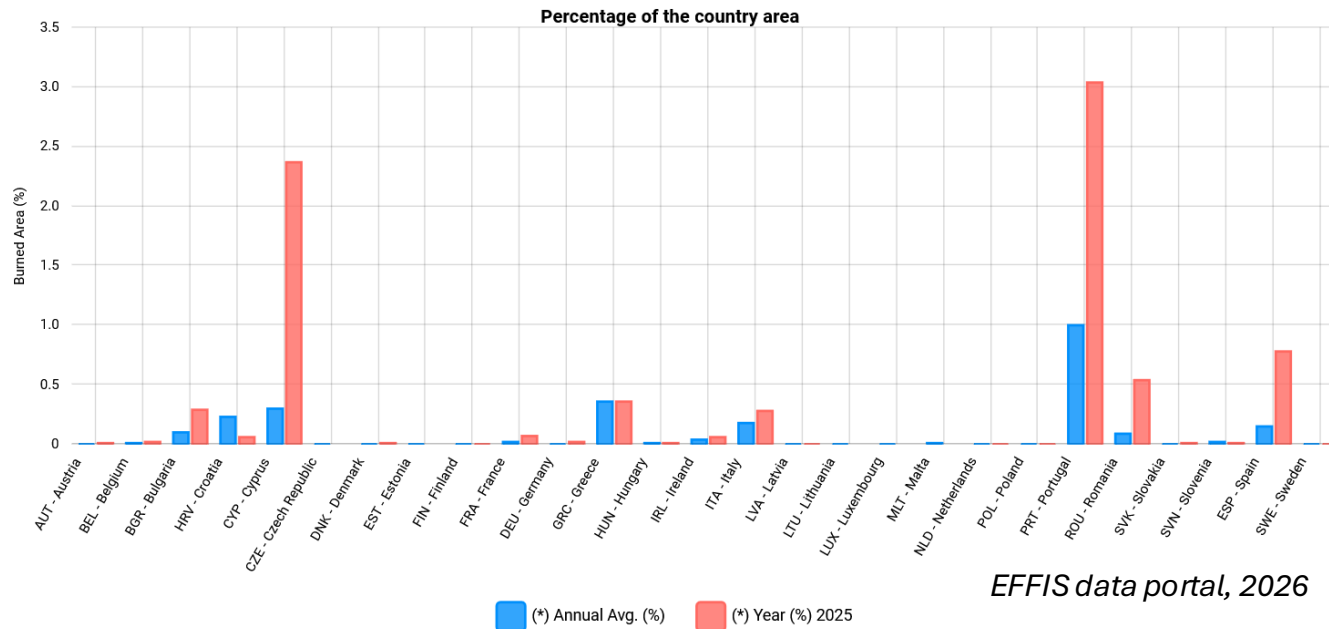
McNorton *et al.*, in review



Sparky Across Scales Case Study

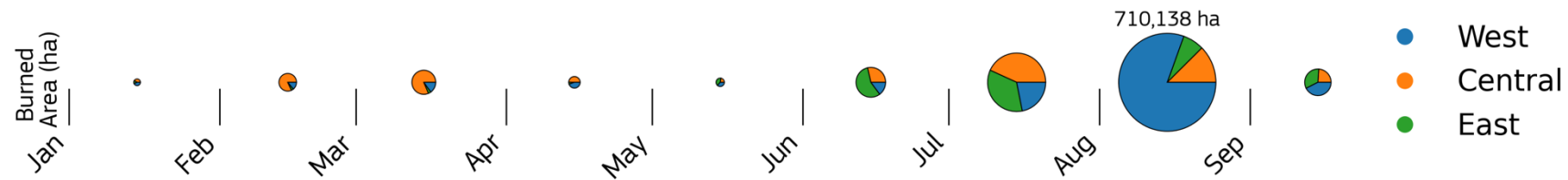


- The Mediterranean 2025 fire season was the biggest in the satellite record (2003-2025) burning over 1,000,000ha.
- Prolonged wildfire period in Eastern Mediterranean with short but more intense period in the Iberian Peninsula.
- Several individual large-scale events.

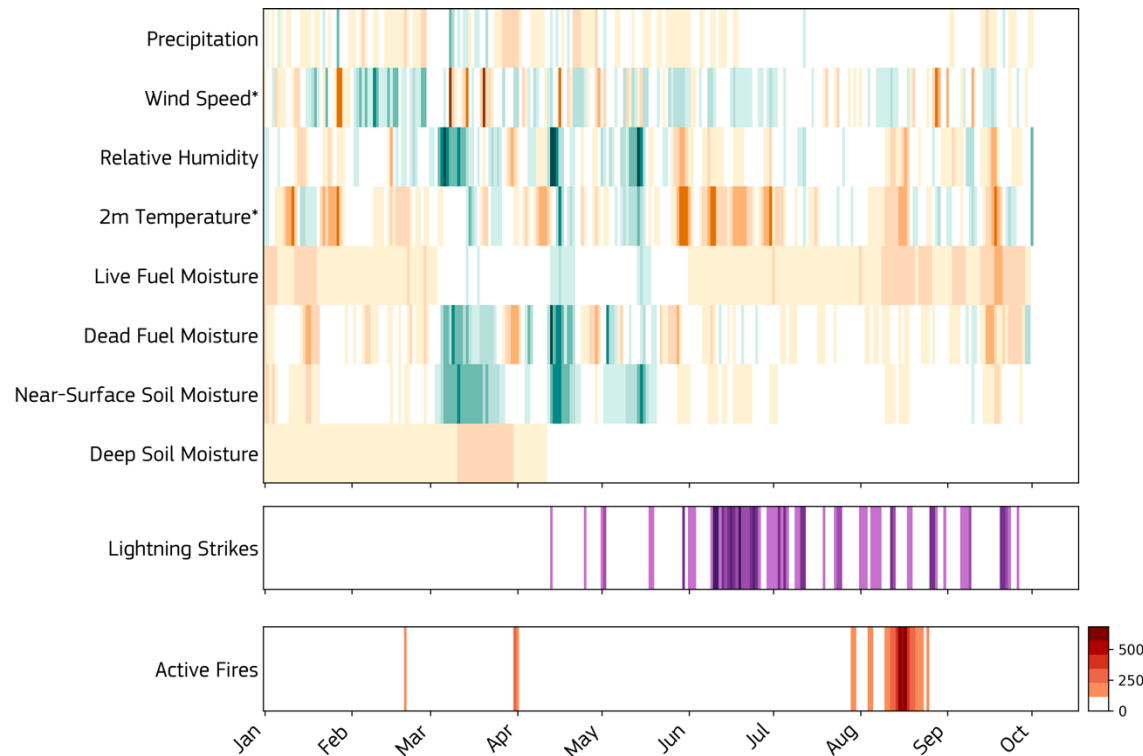


Sparky-Fuel – A Story of Hydroclimatic Rebound

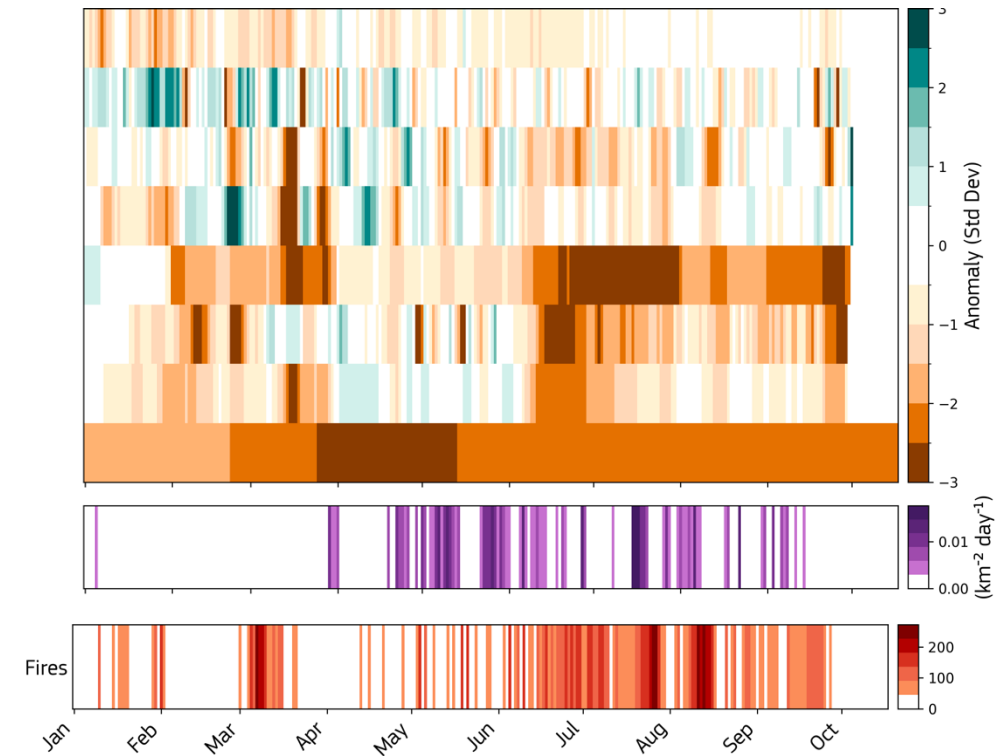
Mediterranean, 2025



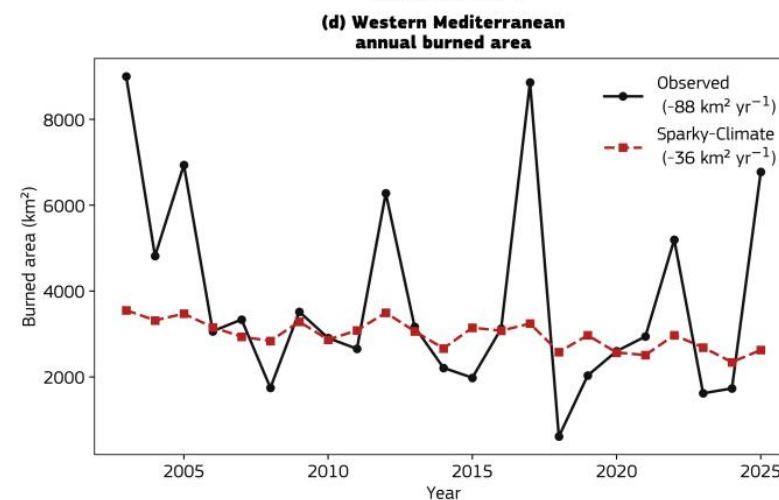
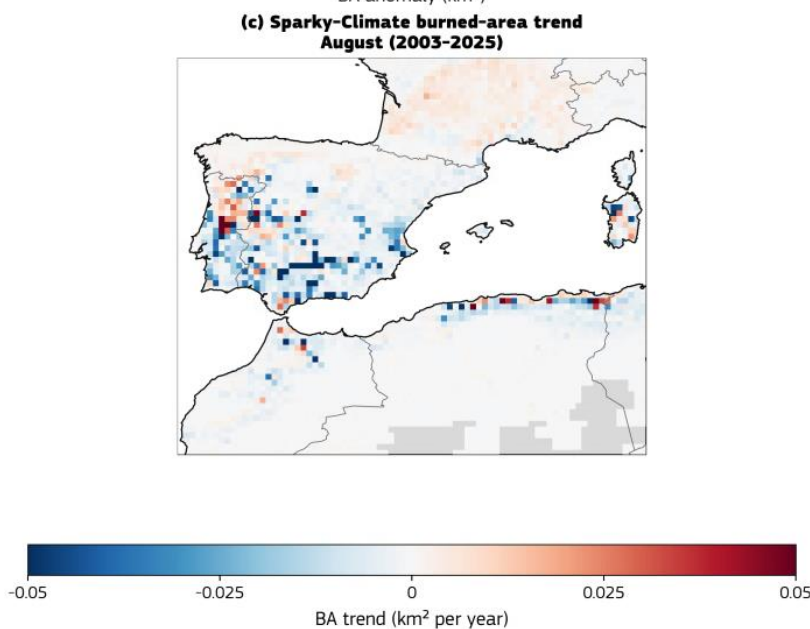
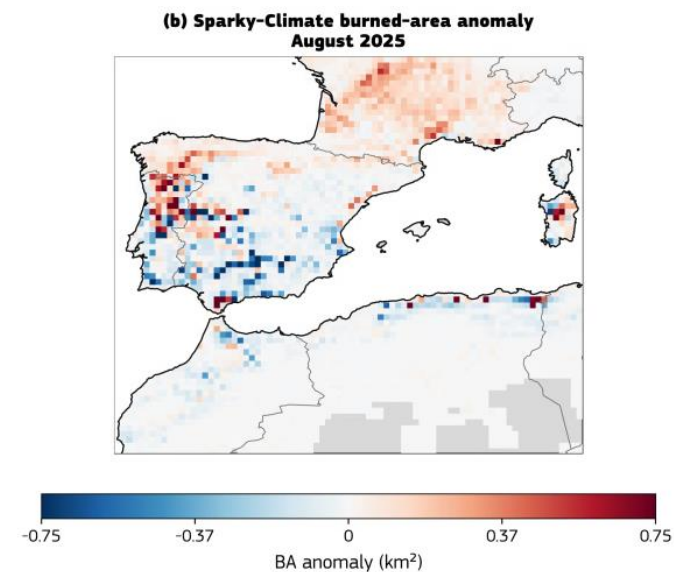
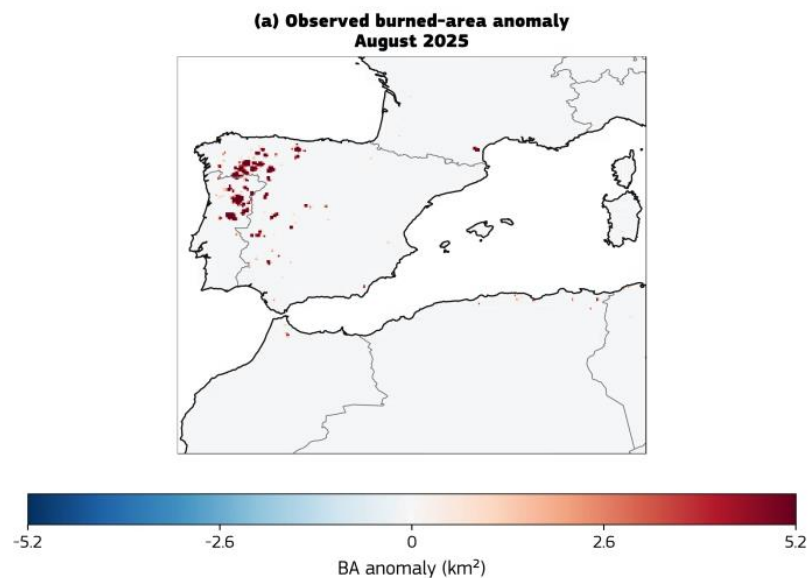
Hydroclimate Rebound in the West Short but Intense Fire Season



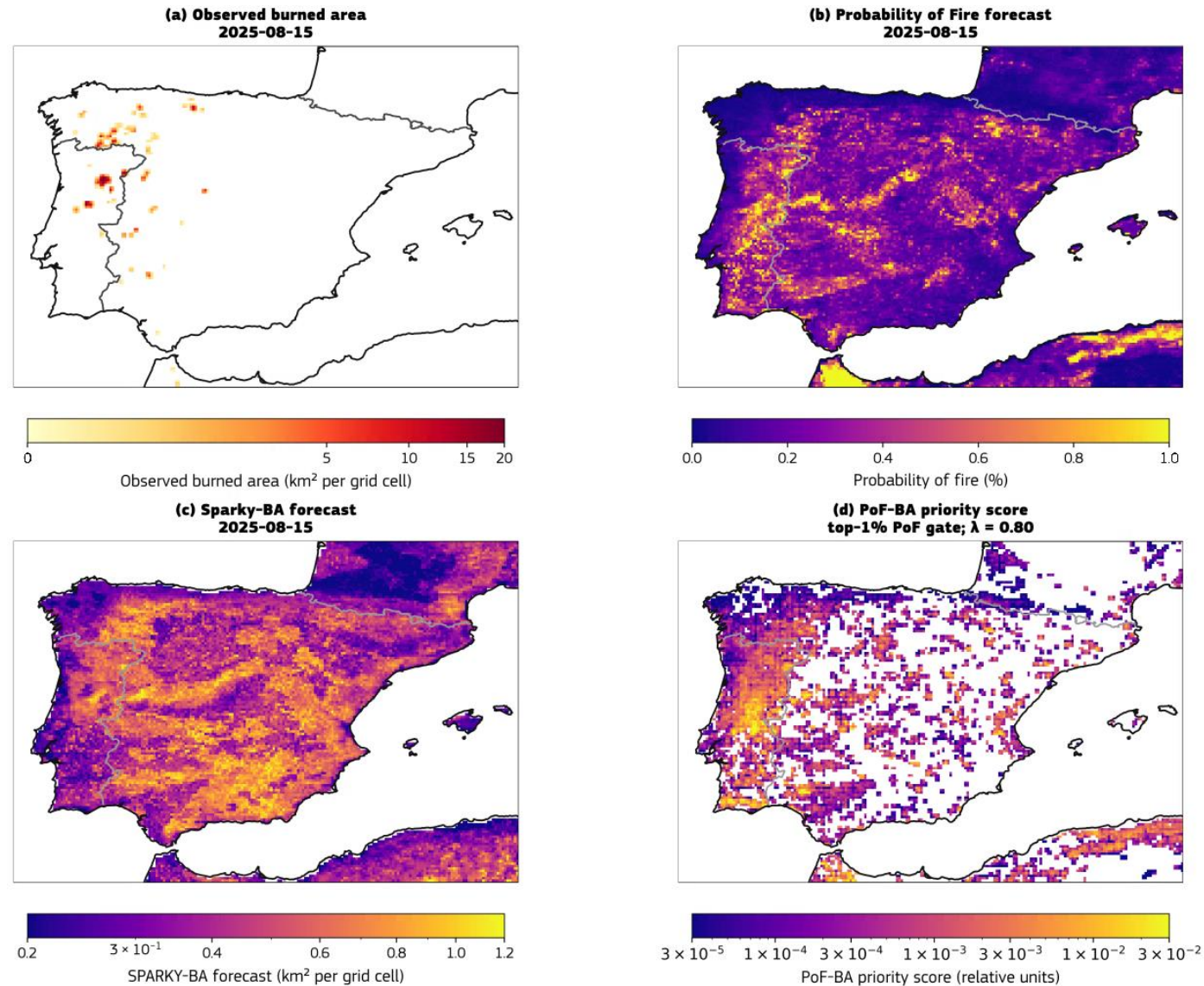
Prolonged Drought in the East Sustained Fire Season



Sparky-Climate – A Story of Anomalies and Trends

McNorton *et al.*, in prep

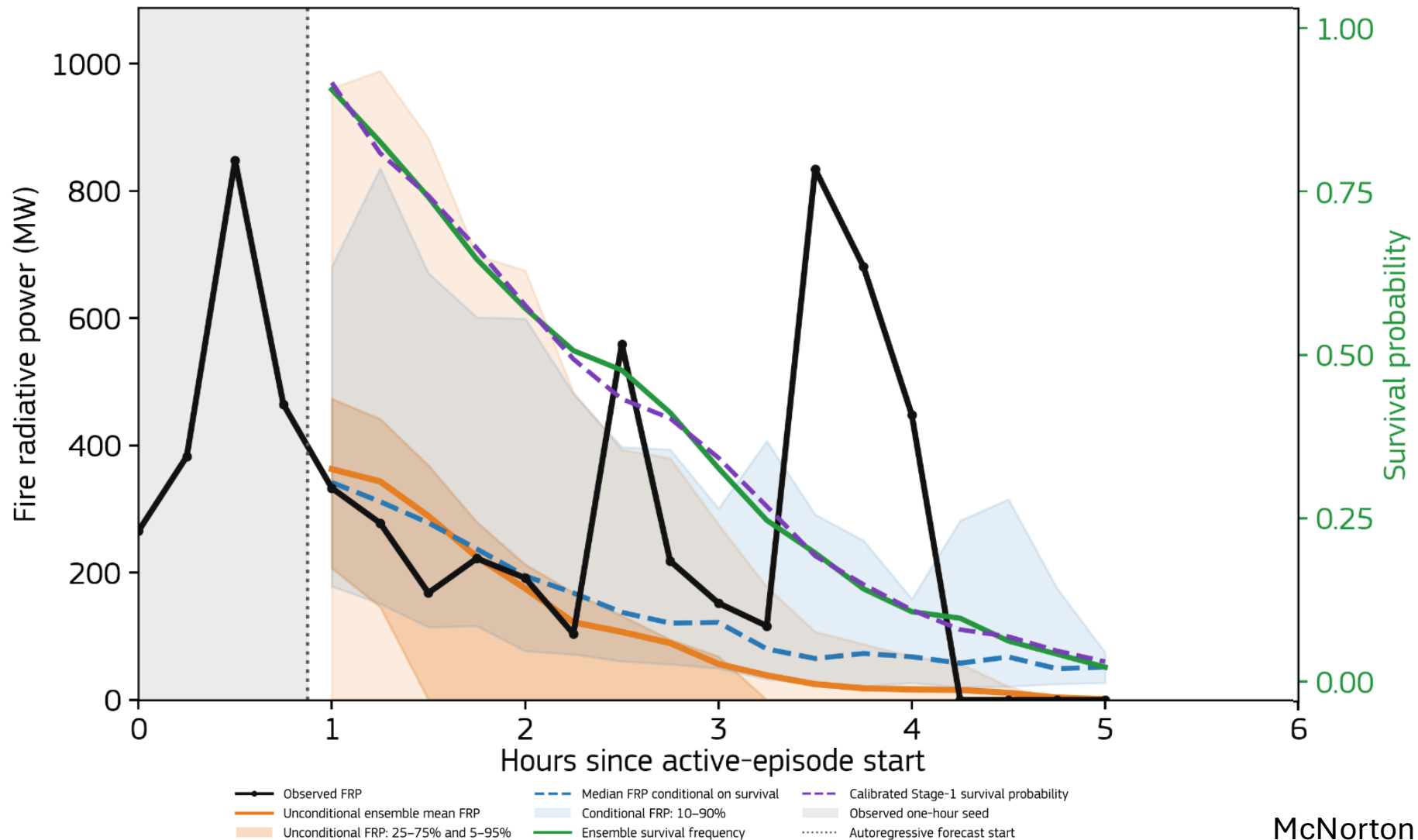
Sparky-Danger – A Story of Extremes



Sparky-Evolve – A Story of Molezuelas de la Carballeda

Mediterranean, 2025

(a) 11 Aug 2025, 14:15
42.11°N, -6.12°E; 1565.8 MWh (4.2 h observed)



McNorton *et al.*, in prep

Conclusions

- Sparky aims to deliver a harmonised framework of wildfires across scales to inform multiple end users.
- Each component delivers a low-cost output for timely dissemination.
- Sparky-Fuel consists of both physical and AI models to simulate multiple fuel characteristics across scales.

Hourly-Daily

Sparky-Evolve provides a real-time FRP evolution at 1km resolution for global/European application.

Use

- Real-time monitoring for evacuations/suppression etc.
- Emissions forecasting.

Daily-Seasonal

Sparky-Danger provides a forecast for fire danger at 1/9 km resolution.

Use

- Strategic level resource deployment.
- Mitigation enactment

Seasonal-Decadal

Sparky-Climate is intended to identify trends and anomalies in fire behaviour.

Use

- Climate analysis/projections
- Risk assessment for industry

Further Information

- Sparky-Fuel

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A global fuel characteristic model and dataset for wildfire prediction

Joe R. McNorton¹ and Francesca Di Giuseppe²

<https://xds.ecmwf.int/datasets/derived-fire-fuel-biomass>

Biogeosciences

Open Access

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- Sparky-Evolve

Details in paper in preparation.

- Sparky-Danger

Geophysical Research Letters*

Research Letter | [Open Access](#) |

A Global Probability-Of-Fire (PoF) Forecast

J. R. McNorton ✉, F. Di Giuseppe, E. Pinnington, M. Chantry, C. Barnard

First published: 14 June 2024 | <https://doi.org/10.1029/2023GL107929>

nature communications

Article | [Open access](#) | Published: 01 April 2025

Global data-driven prediction of fire activity

Francesca Di Giuseppe ✉, Joe McNorton ✉, Anna Lombardi & Fredrik Wetterhall

- Sparky-Climate

Global fuel and burned area reconstructions and projections for 1950–2100

Joe McNorton¹, Edward Comyn-Platt¹, Francesca Di Giuseppe¹, Chiara Cagnazzo², Chris Barnard¹

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Correspondence to: Joe McNorton (joe.mcnorton@ecmwf.int)

<https://xds.ecmwf.int/datasets/projections-fire-fuel-burned-area>

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In review

- Sparky Uses

Global Change Biology

RESEARCH ARTICLE | [Open Access](#) |

Hydroclimatic Rebound Drives Extreme Fire in California's Non-Forested Ecosystems

This article relates to:

Joe McNorton ✉, Alberto Moreno, Marco Turco, Jessica Keune, Francesca Di Giuseppe

State of Wildfires 2023–2024

Earth System Science Data

Matthew W. Jones ✉, Douglas I. Kelley ✉, Chantelle A. Burton ✉, Francesca Di Giuseppe ✉, Maria Lucia F. Barbosa, Esther Brambleby, Andrew J. Hartley, Anna Lombardi, Guilherme Mataveli, Joe R. McNorton, Fiona R. Spuler, Jakob B. Wessel, John T. Abatzoglou, Liana O. Anderson, Niels Andela, Sally Archibald, Dolores Armenteras, Eleanor Burke, Rachel Carmenta, Emilio Chuvieco, Hamish Clarke, Stefan H. Deger, Paula M. Fernandes, Louis Gella, Douglas E. Hunsaker, Gita Hunsaker, Sarah Hunsaker

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Douglas I. Kelley ✉, Chantelle Burton ✉, Francesca Di Giuseppe ✉, Matthew W. Jones ✉, Maria L. F. Barbosa, Esther Brambleby, Joe R. McNorton, Zhongwei Liu, Anna S. I. Bradley, Katie Blackford, Eleanor Burke, Andrew Ciavarella, Enza Di Tomaso, Jonathan Eden, Igor José M. Ferreira, Lukas Fiedler, Andrew J. Hartley, Theodore R. Keeping, Seppe Lampe, Anna Lombardi, Guilherme Mataveli, Yuquan Qu,

Sparky-Fuel

- Total fuel load is then partitioned between live and dead fuel based on PFT over the entire period (2003-2025) based on static literature assumptions.

Land Cover	Average Live %	Land Cover	Average Live %	Land Cover	Average Live %
Crops	85%	Evergreen Needle	65%	Bare Ground	50%
Short Grass	85%	Deciduous Needle	55%	Semidesert	65%
Mixed Crop	85%	Evergreen Broad	85%	Tundra	75%
Irrigated Crops	85%	Deciduous Broad	60%	Bogs/Marshes	65%
Evergreen Shrub	70%	Savannah	80%	Inland Water	0%
Deciduous Shrub	65%	Interrupted Forest	60%	Water-Land	50%

Sparky-Fuel

Land Cover	Dead Foliage %	Land Cover	Dead Foliage %	Land Cover	Dead Foliage %
Crops	100%	Evergreen Needle	45%	Bare Ground	50%
Short Grass	100%	Deciduous Needle	60%	Semidesert	50%
Mixed Crop	100%	Evergreen Broad	10%	Tundra	50%
Irrigated Crops	100%	Deciduous Broad	90%	Bogs/Marshes	50%
Evergreen Shrub	50%	Savannah	90%	Inland Water	100%
Deciduous Shrub	90%	Interrupted Forest	90%	Water-Land	50%