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Drivers of wildland fire behaviour variation across the Earth

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Introduction

Global **fire behaviour patterns and drivers** are incompletely understood and systematized, constraining:

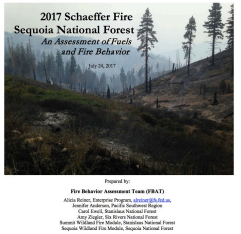
- Fire activity prediction at different temporal and spatial scales
- Anticipation of fire activity response to global change
- Formulation of fire management policies to cope with fire regime changes

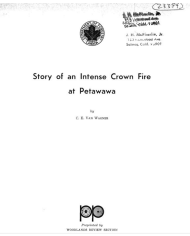
BONFIRE – gloBal-scale analysis and mOdelliNg of FIRE behaviour potential

- Worldwide compilation of fire behaviour data
- Integrated analysis of variation in fire behaviour characteristics to describe patterns, identify and quantify drivers, and improve models.

BONFIRE Data collection

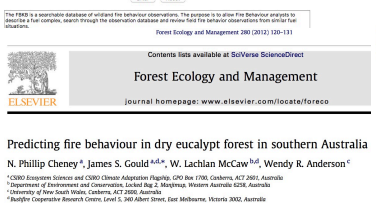
- Scientific publications, technical reports, case studies, online databases, unpublished data
- Outdoors experimental fires, wildfires, and prescribed fires
  - Natural fuels: flaming, smouldering (peat)
  - Anthropic fuels (slash, mastication, crop stubble)
- Headfires, point- or line-ignited, no interaction between fire fronts

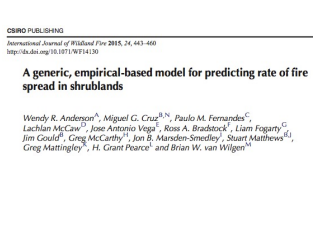


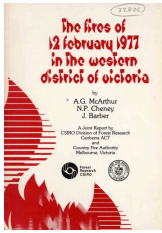


Fire Behavior and Crop-tree Damage Survey

Plot Type	Plot	Date Burned	Ignition time	Reached end of plot	Rate of Spread (ft/min): Range
Low Intensity Plots	2L2	03/09/83	1520	1648	0.8-3.5
Low Intensity Plots	4L1	03/11/83	1420	1533	1.4-3.6
Low Intensity Plots	9L4	03/09/83	1022	1146	0.6-2.3
Low Intensity Plots	11L3	03/11/83	1205	1340	0.5-3.0
Moderate Intensity Plots	3M3	03/04/83	1223	1343	1.3-3.8
Moderate Intensity Plots	7M4	03/04/83	1323	1437	0.9-2.9
Moderate Intensity Plots	8M1	03/09/83	1320	1438	1.7-4.0
Moderate Intensity Plots	10M2	03/04/83	1432	1532	1.7-3.9







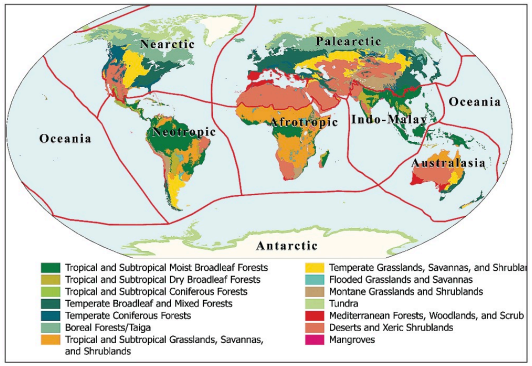
- **Variables**
  - Ancillary data (country, location, fire typology, climate- and vegetation-related, …)
  - Weather variables and fuel moisture contents or surrogates
  - Terrain slope
  - Fuel characteristics (type, heights/depths, cover, loads, % curing, % dead)
  - Fire behaviour characteristics: forward rate of spread, flame characteristics, fireline intensity
  - Fuels consumption (absolute and relative)

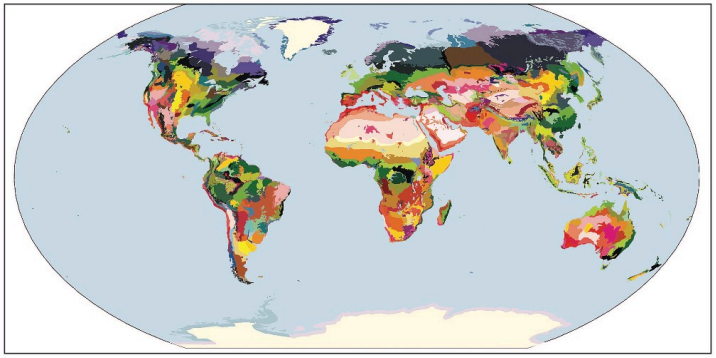
BONFIRE Data collection

Koppen-Geiger climate type

WorldClim Version 2.0 (Fick & Hijmans, 2017): gridded global **climate data** at 1 km^2 resolution

Biomes and **Ecoregions** (Olson et al., 2001)





Broad Vegetation Type (Forest, Woodland, Shrubland, Grassland)

Cover Types (Plant Functional Types)
Combined NCAR LSM surface types with IGBP DISCover cover types (Bonan et al., 2002)

Broad Fuel Type (e.g. Eucalypt Forest)

Dominant species

Fuel Complex (e.g. Litter-Shrub)

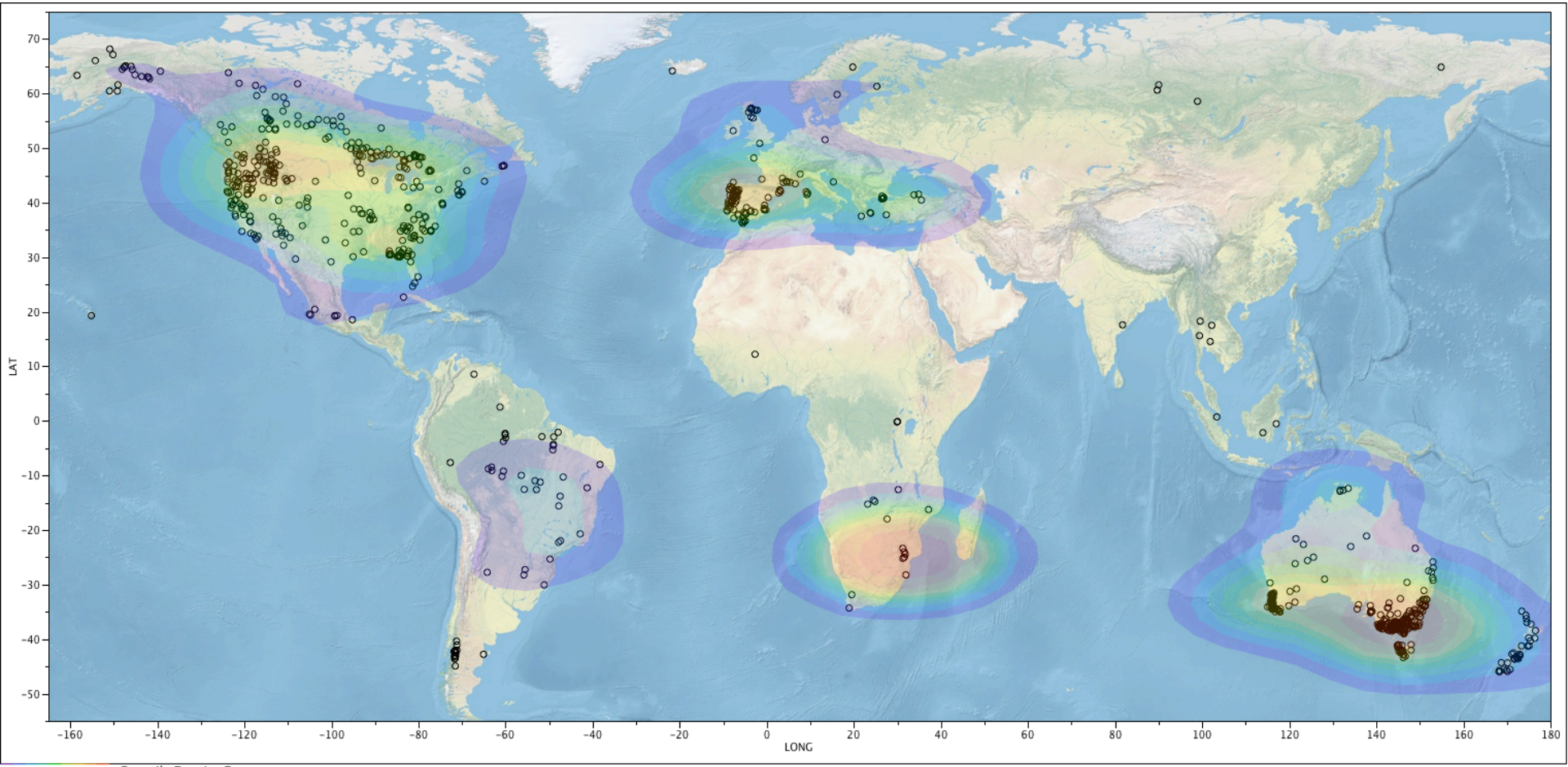
Data

Fire typology	n
Experimental	4313
Prescribed fire	695
Wildfire	912

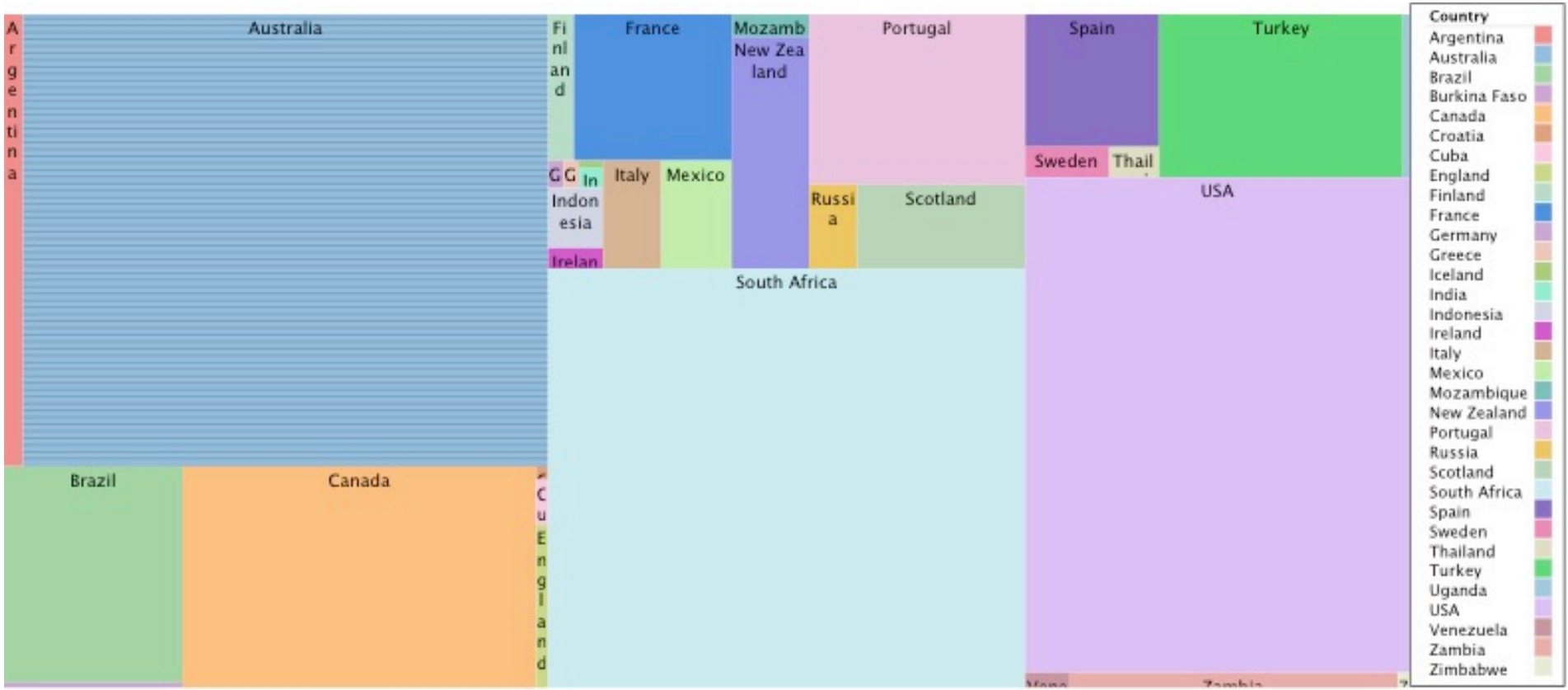
Broad Vegetation Type	*n*
Forest	2490
Grassland	1220
Shrubland	735
Woodland	1475

	n
Fire observations	5920
Rate of spread	5115
Flame height	1368
Flame length	1275
Fireline intensity	4414
Fine fuel consumption	3533
Total fuel consumption	4157

Biome	*n*
Boreal Forests/Taiga	311
Deserts and Xeric Shrublands	187
Flooded grasslands and savannas	15
Mediterranean Forests, Woodlands, and Scrub	**831**
Montane Grasslands and Shrublands	24
Temperate Broadleaf and Mixed Forests	**1647**
Temperate Coniferous Forests	**814**
Temperate Grasslands, Savannas, and Shrublands	289
Tropical and Subtropical Coniferous Forests	46
Tropical and Subtropical Dry Broadleaf Forests	14
Tropical and subtropical grasslands, savannas and shrublands	**1615**
Tropical and Subtropical Moist Broadleaf Forests	119
Tundra	8



Data


Argentina
Australia
Brazil
Canada
England
Finland
France
Mozambique
New Zealand
Portugal
Spain
Turkey
Sweden
Thailand
Indonesia
Italy
Mexico
Russia
Scotland
South Africa
USA
Country
Argentina
Australia
Brazil
Burkina Faso
Canada
Croatia
Cuba
England
Finland
France
Germany
Greece
Iceland
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Indonesia
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New Zealand
Portugal
Russia
Scotland
South Africa
Spain
Sweden
Thailand
Turkey
Uganda
USA
Venezuela
Zambia
Zimbabwe

Objective

How do fire behaviour characteristics vary globally and respond to environmental drivers?

Data pre-treatment

- Wind speed adjustment (2m, 6m, 10m heights)
- Dead fine fuel moisture content estimation
- Rate of spread (*R*) correction for 0º slope (Van Wagner 1977; Sullivan et al. 2014)
- *R* adjusted for an ignition line length *W* of 100 m after fitting

  $R = 2.564\ U_{10}^{1.094} * \exp(-0.102\ M_f)$ **$(1-\exp(-0.048\ W))$**

  where U_{10} = 10-m open wind speed (km h^{-1}) and M_f = fine dead fuel moisture content (%)
- Byram's fireline intensity (kW m^{-1}) standardized as $R * w_f * 18{,}000$ kJ kg^{-1}

  with *R* in m s^{-1} and w_f = fine fuel consumption (kg m^{-2})

Data analysis

- Exploration: descriptive stats and regression tree analysis
- Generalized linear models sequentially fitted to log-transformed fire behaviour variables (R, w_f) from climate, weather and fuel descriptors*:

Climate:

Temperature + Precipitation + Biome

Temperature + Precipitation + Broad Vegetation Type

Temperature + Precipitation + Cover Type

Climate + Weather:

Temperature + Precipitation + Cover Type + U + M_d / M_{d+l}

Climate + Weather + Fuel:

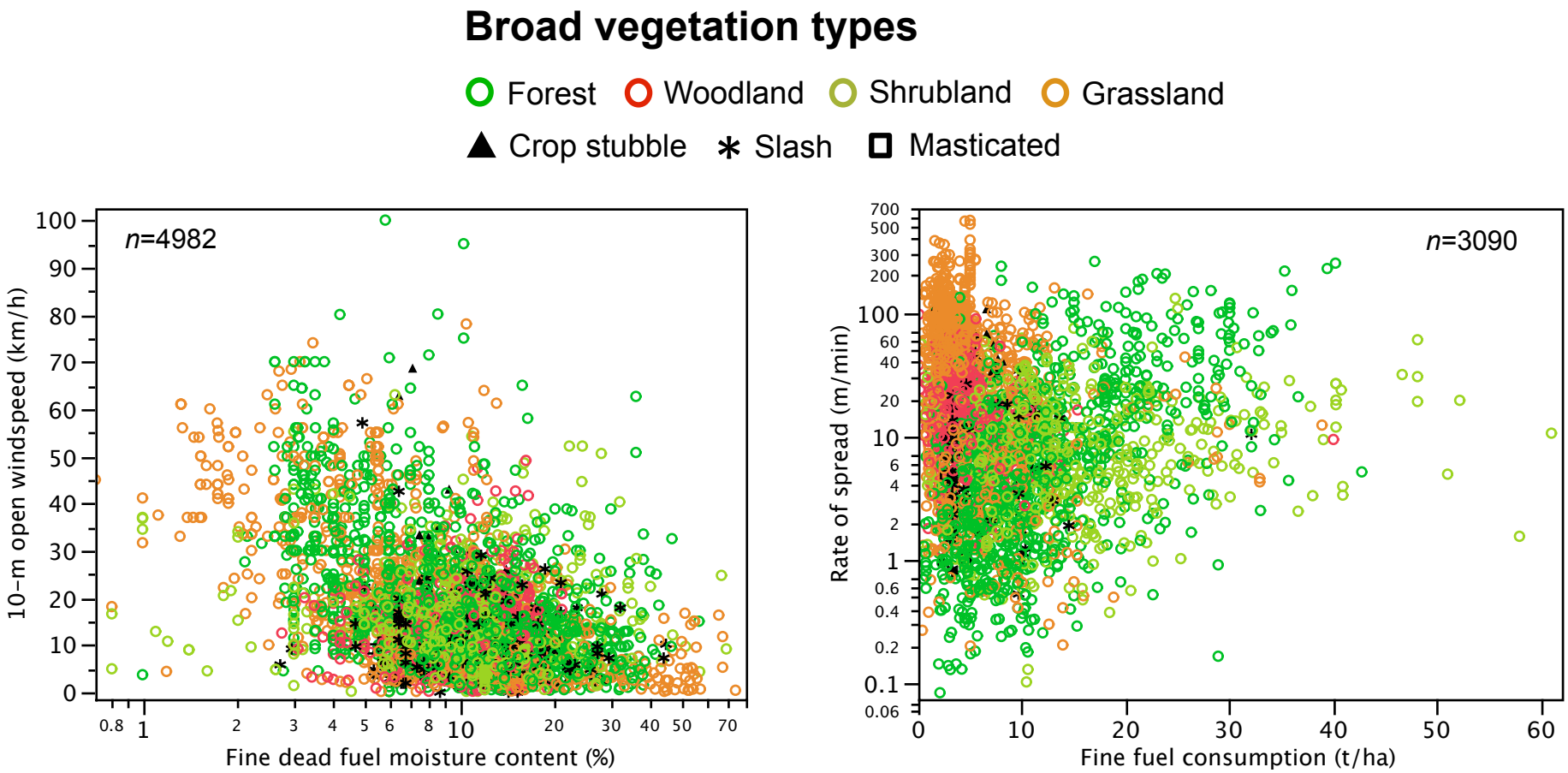
Temperature + Precipitation + Broad Fuel Type + Fuel Complex + U + M_d / M_{d+l}

Temperature + Precipitation + Broad Fuel Type + Fuel Complex + Fuel Depth + Fine Dead % + U + M_d / M_{d+l}

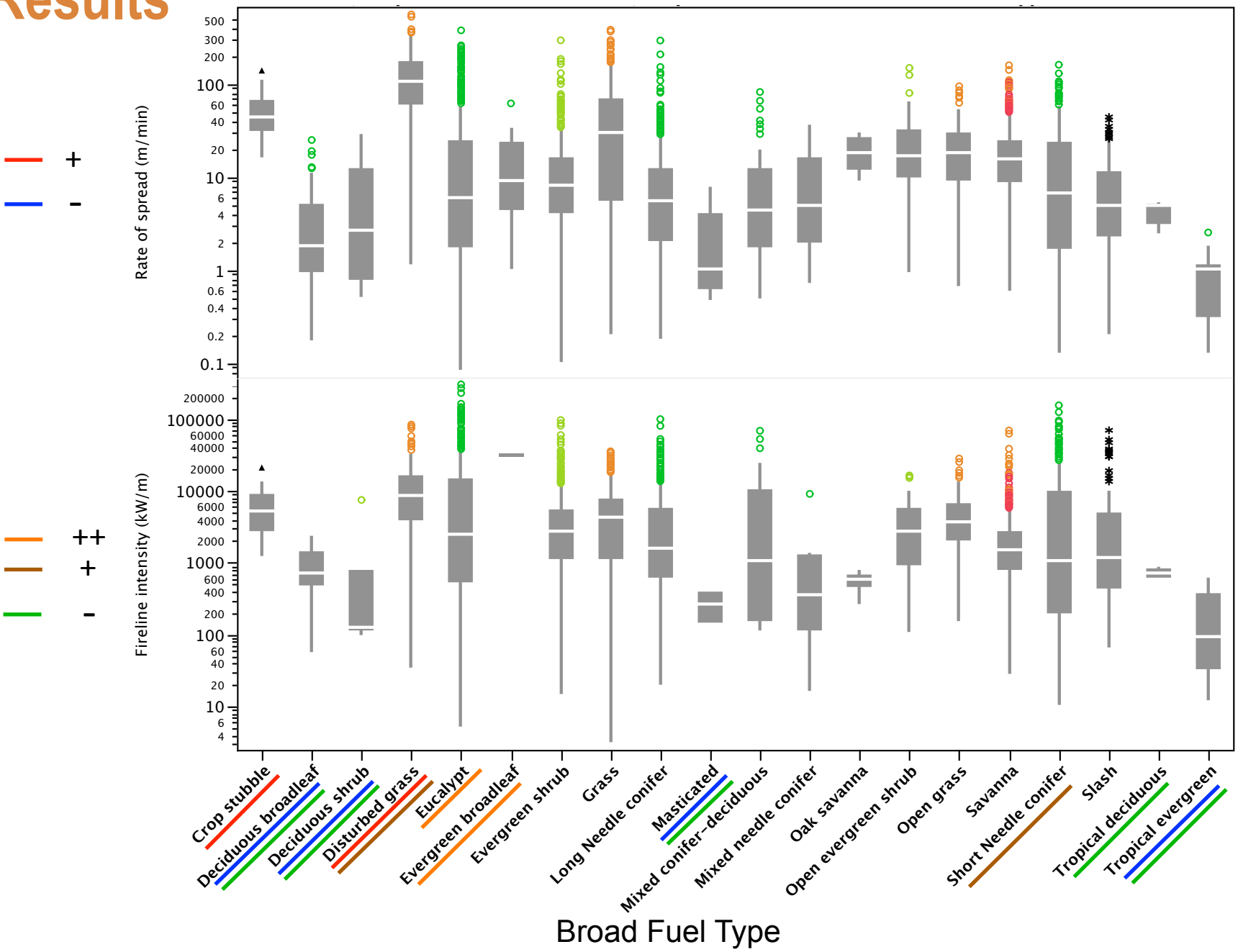
Temperature + Precipitation + Broad Fuel Type + Fuel Complex + Fine Fuel Load + Fine Dead % + U + M_d / M_{d+l}

* Fuel metrics were log-transformed, except moisture content

Results


Broad vegetation types
Forest
Woodland
Shrubland
Grassland
Crop stubble
Slash
Masticated
n=4982
10-m open windspeed (km/h)
Fine dead fuel moisture content (%)
n=3090
Rate of spread (m/min)
Fine fuel consumption (t/ha)

Results


+
-
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+
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Rate of spread (m/min)
Fireline intensity (kW/m)
Crop stubble
Deciduous broadleaf
Deciduous shrub
Disturbed grass
Eucalypt
Evergreen broadleaf
Evergreen shrub
Grass
Long Needle conifer
Masticated
Mixed conifer-deciduous
Mixed needle conifer
Oak savanna
Open evergreen shrub
Open grass
Savanna
Short Needle conifer
Slash
Tropical deciduous
Tropical evergreen
Broad Fuel Type

Results

Fire spread rate

Relative amount of explained variability (%)

Independent variables	Climate			Climate + Weather		Climate + Weather + Fuel			
Temperature	31.3	5.8	3.2	0.8	4.6	0.6	4.0	5.8	9.2
Precipitation	22.4	9.8	11.9	n.s.	2.7	n.s.	1.1	n.s.	1.0
Biome	**46.3**								
Broad Vegetation Type		**84.3**							
Cover Type			**84.9**	22.1	**39.5**				
Broad Fuel Type						12.9	28.5	16.1	17.8
Fuel Complex						9.5	11.6	12.6	15.2
Fuel Depth								5.1	9.4
Fine Dead %								13.3	15.3
Dead Fuel Moisture				20.5		21.3		11.4	
Weight. Dead+Live Fuel Moisture					12.8		14.8		0.5
Wind Speed				**56.6**	**40.3**	**55.6**	**40.0**	**35.6**	**31.6**
R^2	0.173	0.216	0.238	0.503	0.468	0.531	0.504	**0.697**	0.629

Relative explanations (%)
Best (most complete) model

Climate = 5.8
Weather = 47.0
Climate-Fuel = 28.7
Fuel = 18.5

Results

Fine fuel consumption

Relative amount of explained variability (%)

Independent variables	Climate			Climate + Weather		Climate + Weather + Fuel			
Temperature	n.s.	7.3	2.5	5.9	2.2	4.1	1.0	n.s.	n.s.
Precipitation	20.1	12.7	3.8	6.0	4.3	4.6	3.7	0.5	0.8
Biome	**79.9**								
Broad Vegetation Type		**80.1**							
Cover Type			**93.7**	**87.3**	**86.5**				
Broad Fuel Type						**72.0**	**68.0**	4.0	4.7
Fuel Complex						17.8	21.4	7.3	5.8
Fine Fuel Load								**85.1**	**87.4**
Fine Dead %								2.7	1.3
Dead Fuel Moisture				n.s		n.s.		0.4	
Weight. Dead+Live Fuel Moisture					7.0		5.9		n.s.
Wind Speed				0.7	n.s.	1.5	n.s.	n.s.	n.s.
R^2	0.172	0.282	0.391	0.405	0.412	0.445	0.460	**0.829**	**0.840**

Relative explanations (%)
Best (most complete) model

Climate = 0.5
Weather = 0.4
Climate-Fuel = 11.3
Fuel = 87.8

Fireline intensity

Climate = 4.6
Weather = 31.3
Climate-Fuel = 30.3
Fuel = 33.8

Conclusion

- We globally assessed how the continuum of top-down to bottom-up environmental drivers determine the spread and fuel consumed by a moving fire front.
- Disparate data sources and highly variable data (in methods, completeness, and reliability) did not preclude attainment of consistent results.
- While variation in fire spread rate is mostly determined by climate (indirectly) and weather (directly), variation in fine fuel consumption is governed by local fuel conditions.
- Results are useful for fire research and fire management applications and increase the understanding of fire behaviour changes in relation to global change.
- Further work with the BONFIRE project database:
  - Empirically-based modelling of fire behaviour characteristics and fuel consumption for generic/specific vegetation/fuel types.
  - Development of calibrated fuel models for global use.
  - Improved fire danger rating.

Thank you!

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