Modelling spatial and temporal patterns of fire due to human activity
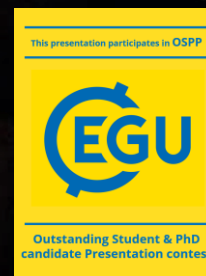
Ol Perkins, James Millington, Sarah Matej, Karl-Heinz Erb

Collaborators:

Matt Kasoar & Apostolos Voulgarakis (modelling);

Cathy Smith & Jay Mistry (meta-analysis);

Rounsevell Group @ KIT (scenario development)

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Contents

Abstract QR

- Overview

  ➤ We have built WHAM! – the <u>W</u>ildfire <u>H</u>uman <u>A</u>gency <u>M</u>odel – a global model of human-fire interactions

  ➤ We have coupled WHAM! with the JULES-INFERNO dynamic global vegetation model

- Top-line outcomes

  ➤ The coupled model suggests about 50% of all global burned area is from small, managed anthropogenic fire

  ➤ The coupled model shows improved quantitative benchmarks

Our starting point: results from FIREMIP

- The Fire Model Intercomparison Project found **anthropogenic impacts on fire were the central causes of disagreement** amongst models, and between models and observations.
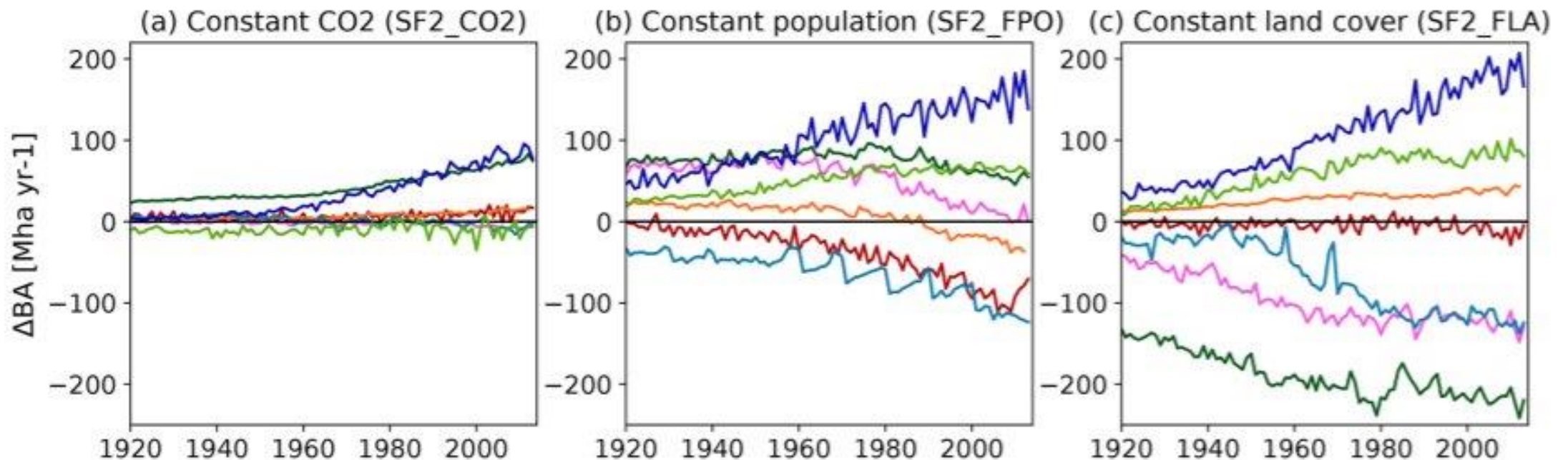

Figure 1: from Teckentrup *et al.* (2019) - Counterfactual scenarios assessing FIREMIP model ensemble sensitivity to atmospheric CO^2, human population and land cover (INFERNO in Orange)

WHAM! land use engine

- We defined four Anthropogenic fire regimes (AFRs) derived from the work of Pyne (2001)

- We combined these with four land use systems (Crops, Livestock, Forestry & Non-extractive)

- The resulting 16 classes are the basis for our distribution of *Agent Functional Types*

- We evaluated land use outputs with independent metrics based on the Human Appropriation of Net Primary Production & found good alignment

Figure 2: Global land-surface coverage of Anthropogenic fire regimes

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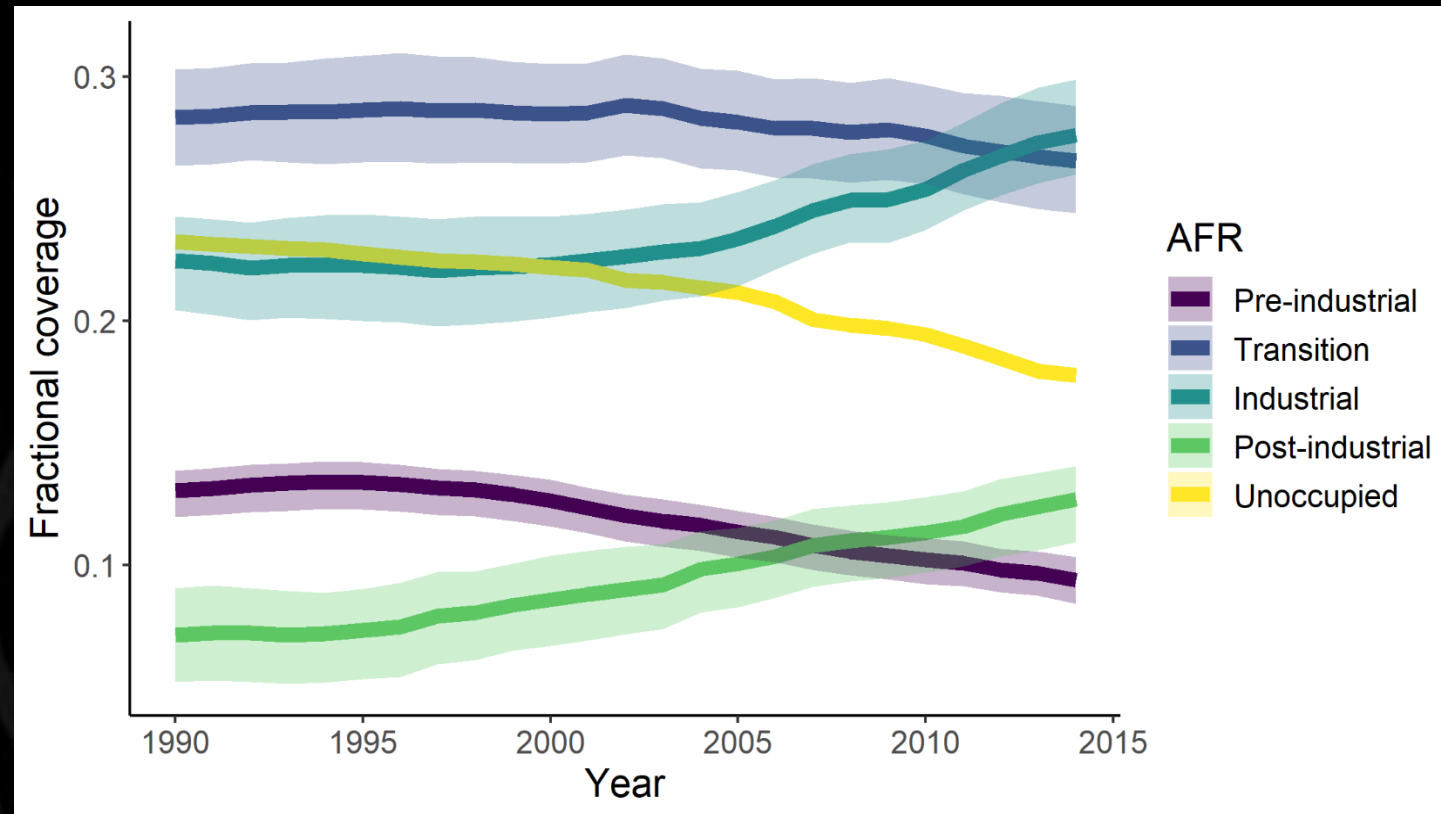
WHAM!: Managed fire outputs

- Model projects 475 Mha of managed fire globally in 1990, reducing to 430 Mha in 2014

- Changes in fire use broadly reflect findings of Smith *et al.* (2022): subsistence-focused fire use (~pasture) is being replaced by market-focused fire use (~arable)
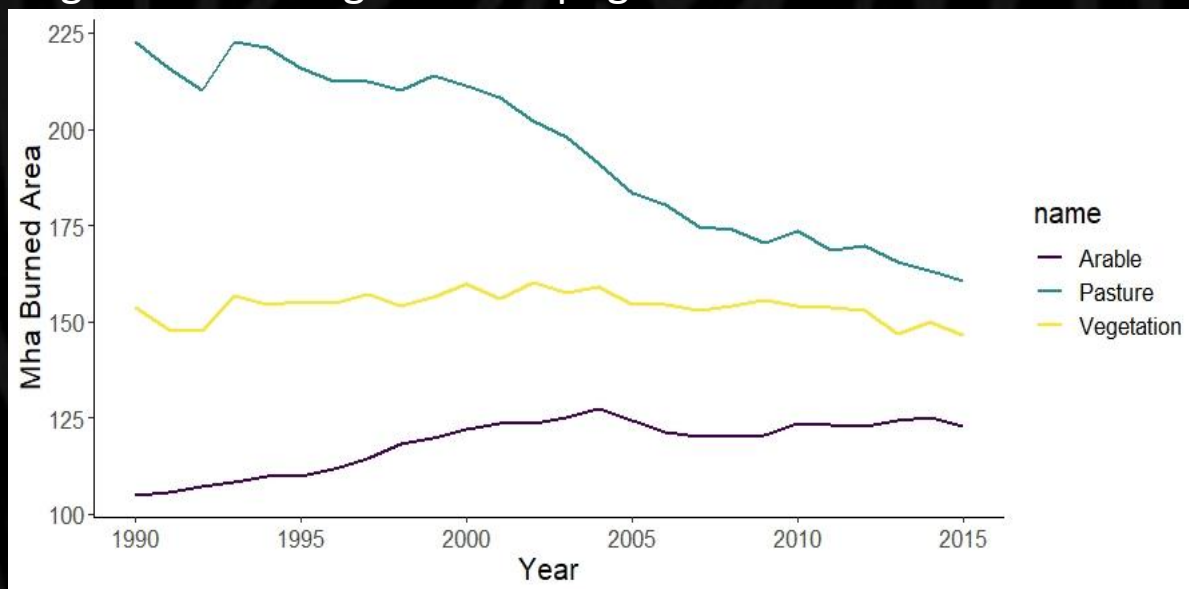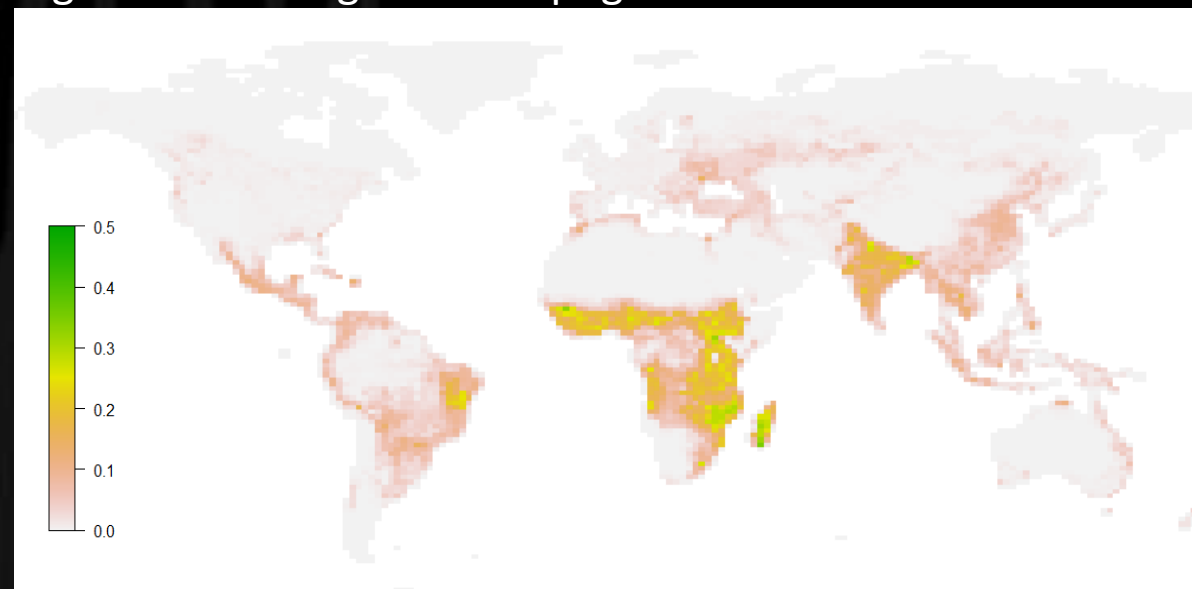
Figure 3a: Managed anthropogenic fire 1990-2014

Figure 3b: Managed anthropogenic fire 2014

(Loosely) Coupled model outputs

- Managed anthropogenic fire accounts for around ½ of global burned area

- Unmanaged fire is comprised of escaped managed fires, arson, lightning fires, and accidental anthropogenic fire
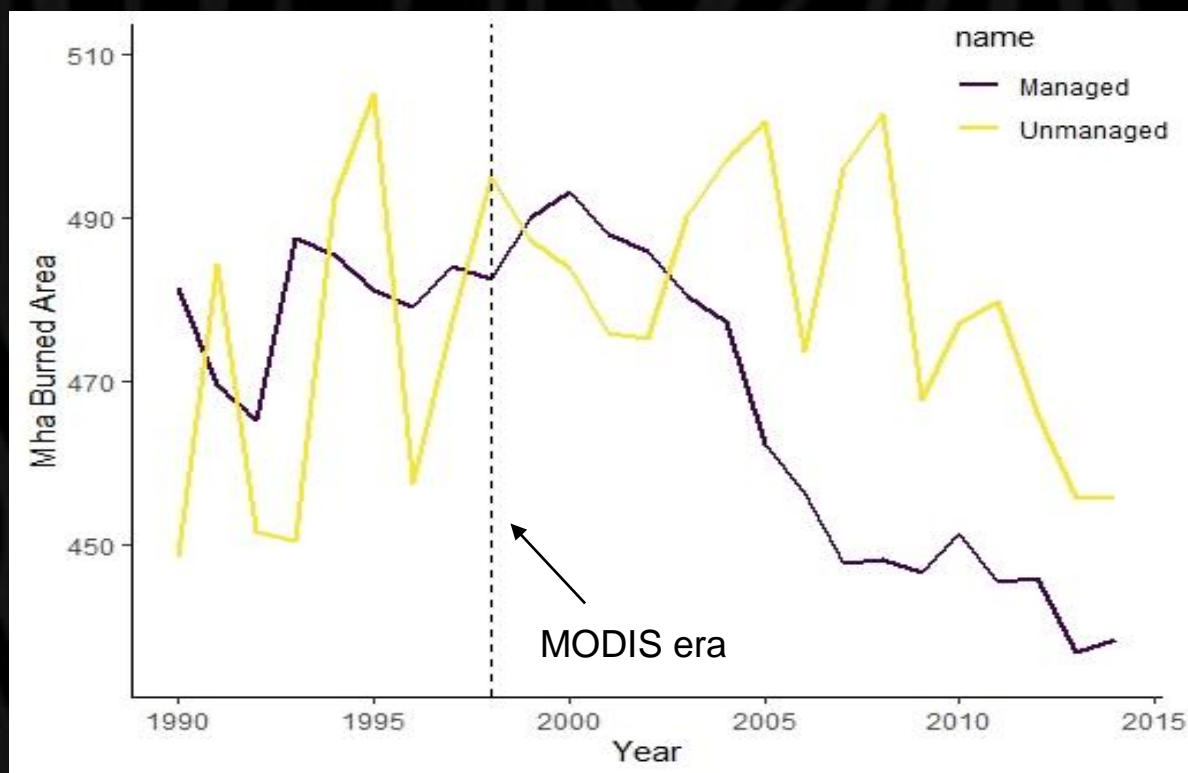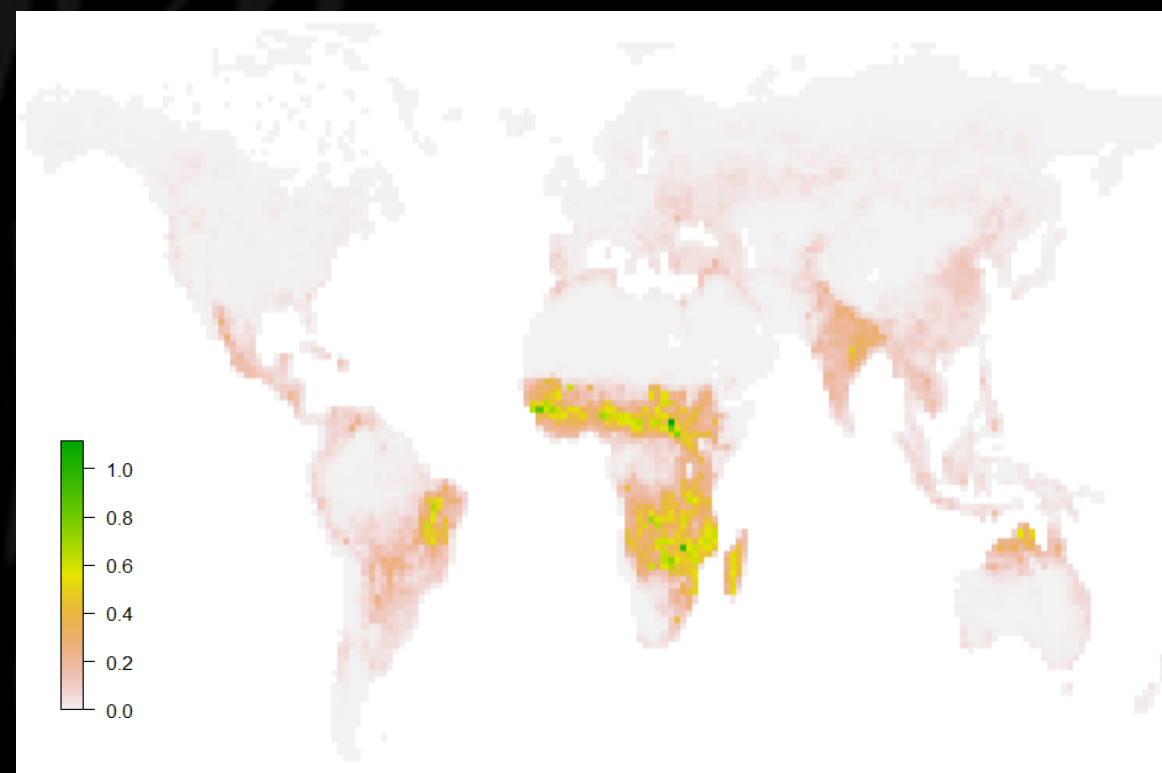
Figure 4a) Burned area 1990-2014

Figure 4b) Burned area 2014

WHAM-INFERNO performance

- Our approach is to calibrate against Sentinel-2, then sanity check against GFED v4.1s
  - ➢ We are explicitly modelling fires that are not captured reliably in GFED data

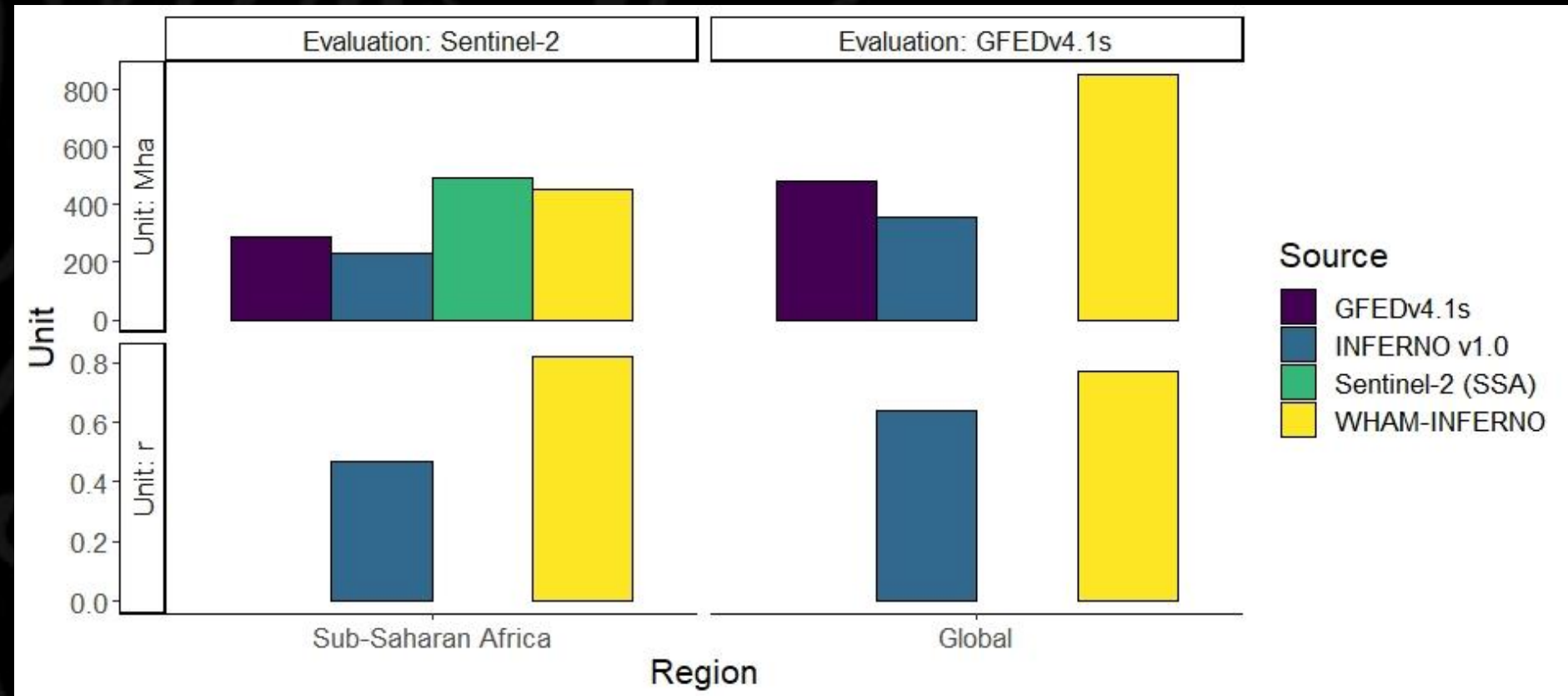- We achieve higher correlation against remote sensing data than INFERNO v1.0

Figure 5: Evaluation of WHAM!-INFERNO ensemble against Sentinel-2 for Sub-Saharan Africa & global comparison with Global Fire Emissions Database (GFED)

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Conclusions

- The loosely coupled ABM-DGVM ensemble we have built provides new insight into the patterns and drivers of fire on Earth

  ➢ **Managed anthropogenic fire accounts for ~50% of global burned area**
  ➢ Residue burning in intensive agriculture increased 1990-2014, whilst fire use for extensive livestock farming decreased

- We are able to capture the distribution of fire in Sentinel-2 data for SSA, whilst the previous iteration of JULES-INFERNO can only do so modestly

  ➢ Global fire modellers should consider how to **benchmark against data that capture small anthropogenic fires**

- We are keen to work with additional biophysical modelling groups
  ➢ **Please get in touch: oliver.perkins@kcl.ac.uk**

Contact & citations

Abstract QR

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Citations:

- Perkins, O., Matej, S., Erb, K.-H., & Millington, J.D.A. 2022. Towards a global behavioural model of anthropogenic fire: The spatiotemporal distribution of land-fire systems. *Socio-Environmental Systems Modelling, vol. 4, 18130, 2022, doi:10.18174/sesmo.18130*

- Smith, C., Perkins, O. & Mistry, J. Global decline in subsistence-oriented and smallholder fire use. *Nature Sustainability*. 2022. https://doi.org/10.1038/s41893-022-00867-y

➢ Data: Perkins, O., & Millington, J. (2021). DAFI: a global database of Anthropogenic Fire. https://doi.org/10.6084/m9.figshare.c.5290792

➢ Code: https://github.com/OliPerkins1987/Wildfire_Human_Agency_Model

Appendices

Principles of agent-based modelling

- Detailed & explicit representation of decision-making, usually by agents representing individuals, households or companies

Ford *et al. (inc. Millington, Perkins). (2021). Front. Env. Sci.* doi: 10.3389/fenvs.2021.649835
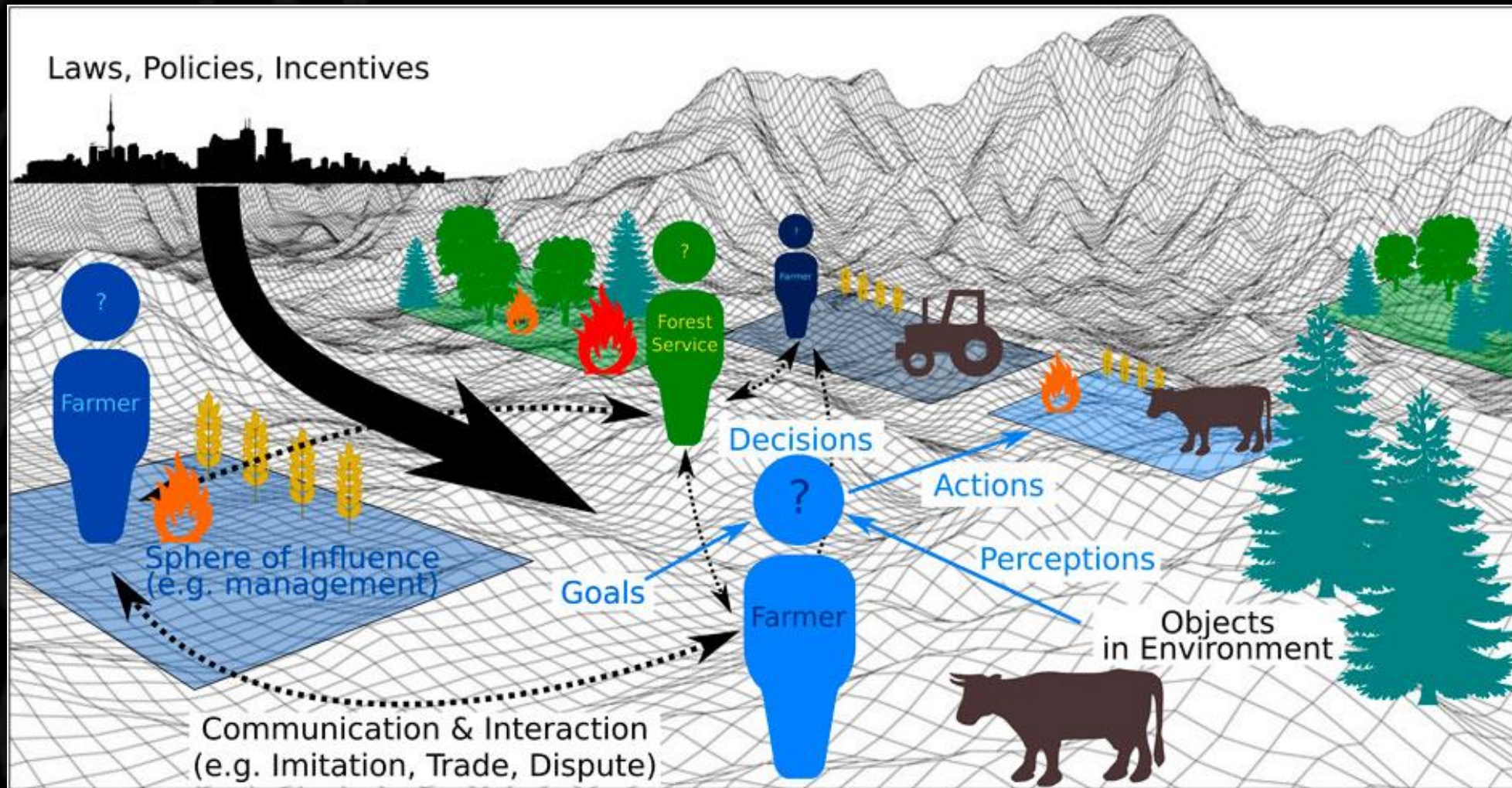
WHAM! mechanics: fire use

- We conducted a meta-analysis of human fire literature, spanning 1809 case studies in 504 papers

- We parameterised our agents for 7 types of fire use based on the resulting data set

- Fire suppression behaviours are parameterised as meta-effects on the landscape (a quasi voting mechanic between agent types)

Fire Use	Median Size (ha)	Mean Burned Area (% LS)	Escaped (%)
Crop Field Preparation	0.7	14.2	0.05
Crop Residue Burning	3.6	36.3	0.01
Pasture Management	10.7	32.1	4.97
Hunter-Gatherer	1.3	14.3	2.90
Pyrome Management	40.8	14.0	0.30
Vegetation Clearing	4.7	2.5	3.23
Arson	N/A	N/A	N/A

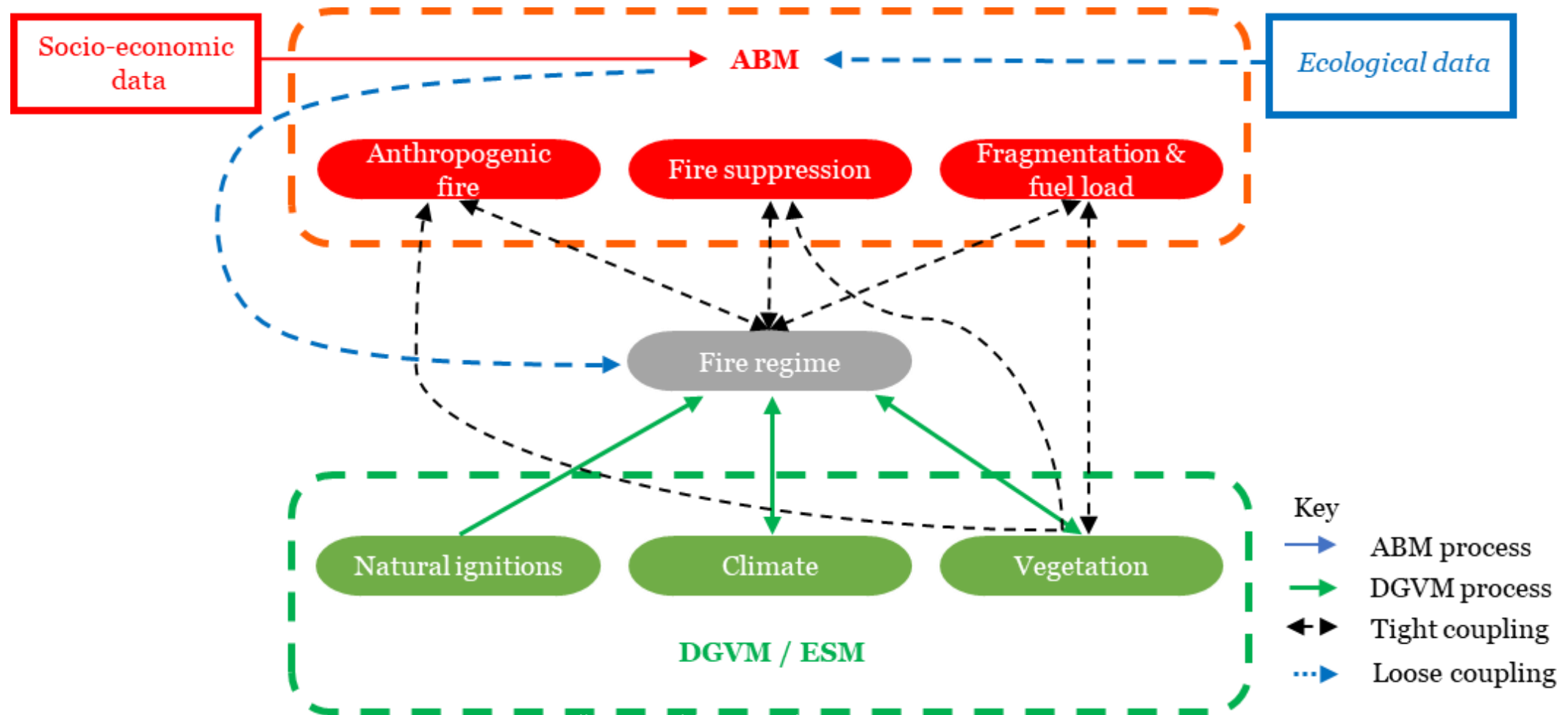Data available at: https://doi.org/10.6084/m9.figshare.c.5290792

Drivers of change in agricultural fire

- Pasture fires decrease exponentially with increased economic growth, as land use intensifies
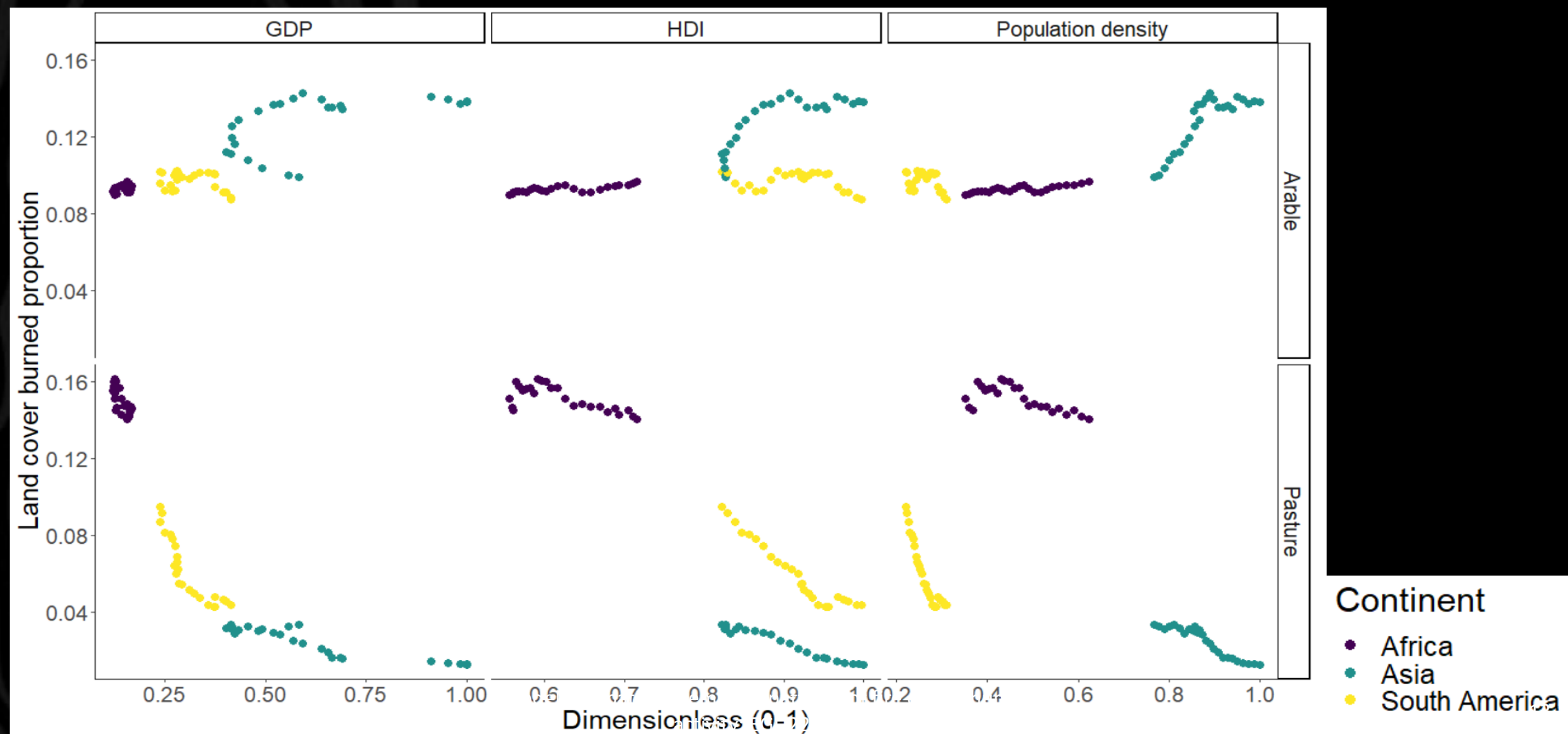
Tight & loose coupling

- We have so far completed a loose (offline) coupling of WHAM (ABM) and JULES-INFERNO (DGVM)
- Our goal is to progress to a tight or fully-coupled ensemble

Ford *et al. (inc. Millington, Perkins). (2021). Front. Env. Sci.* doi: 10.3389/fenvs.2021.649835

Knowledge gap: livestock systems

➢ **Pasture management accounts for ~250 Mha burned area globally over our historical period**

- However, livestock systems' distribution is uncertain: particularly on semi-natural rangelands

- There is some evidence in the literature that fire use is different for cattle vs goats

- This also makes implementation of fragmentation effects of grazing complex to implement

Correlation of modelled land system distribution & UN livestock data (2010)