LEVERHULME
Centre for Wildfires, Environment and Society

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ATMOSPHERIC ENVIRONMENT & CLIMATE CHANGE LAB

Wildfires, climate, and the hydrological cycle

Leverhulme Wildfires Summer Conference 2023
Imperial College London, South Kensington Campus

Manolis Grillakis and **Apostolos Voulgarakis**

Laboratory of Atmospheric Environment and Climate Change

Technical University of Crete

Department of Physics, Leverhulme Centre for Wildfires, Environment and Society, Imperial College London, London, UK

Fields of study

- Modelling of interactions between air pollution (aerosols & gases) and climate.
- The role of fire in the Earth system (global, high latitudes, tropical, Mediterranean), including global fire modelling.
- Using satellite data in conjunction with models to understand processes in the Earth system (incl. fire).
- Using machine learning in climate science and fire science problems.

Projects within the Leverhulme Centre for Wildfires

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Global and large-scale projects:

- Past/Future global radiative forcing of fire aerosols (**Matt Kasoar – recently, Rafaila Mourgela**)
- Influence of fire-generated air pollutants on El Niño prediction (**Matt Kasoar**)
- Skill of FireMIP models in capturing high-latitude fires (**Matt Kasoar**)
- Including high-latitude peat fires and their emissions in UKESM (**Katie Blackford**)
- High latitude fires and feedbacks with air pollution and climate (**Eirini Boleti, Dimitra Tarasi**) AXA
- Coupling fire with atmospheric composition in UKESM (**João Teixeira – based at MetO/Exeter**)
- Hydrological impacts of wildfires in different world regions (**Manolis Grillakis**)

- Climate drivers of global wildfire burned area (**Manolis Grillakis**)
- Effects of vegetation on driving global burnt area using machine learning (**Alex Kuhn-Regnier**)
- Impacts of African fire aerosol emissions on air quality and climate (**Chris Wells**)

Projects within the Leverhulme Centre for Wildfires

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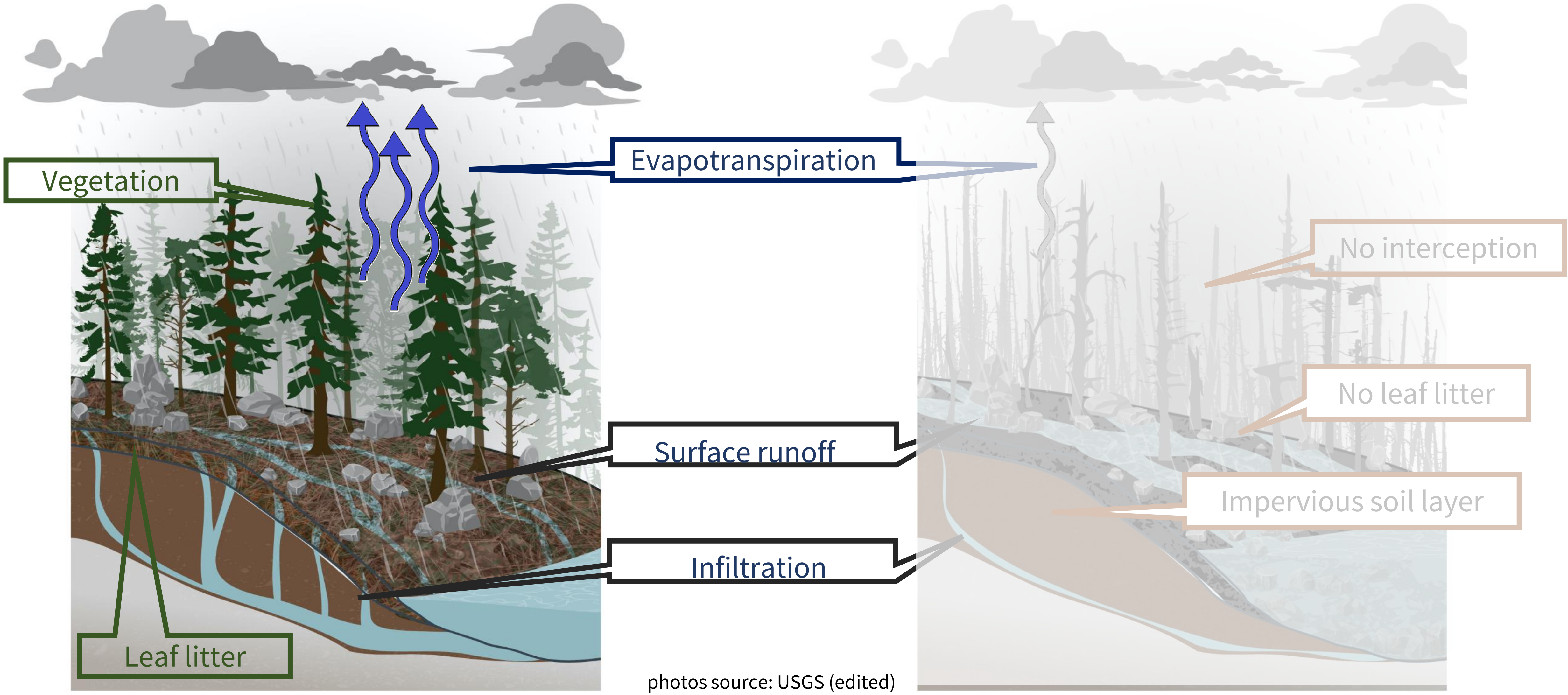
Regional projects (Greece / Mediterranean)

- Climate change impacts on future wildfire danger in Greece (**Tasos Rovithakis**)
- Fire aerosols and weather feedbacks over Greece (**Tasos Rovithakis**)
- Using fractal theory to simulate fire spread for major Greek fires (**Iulian Rosu**)
- Enhancing detection skill and information flow in the case of a fire event in the Samaria National Park, Crete (**Manolis Grillakis**)
- Calibrating the FWI over the Mediterranean region (**Panagiotis Angelis**)
- Assessing the skill of the FWI to capture observed burnt areas for Greece (**Anastasia Demiroglou**)

Wildfires effects on the hydrological cycle

Wildfires and the hydrological cycle

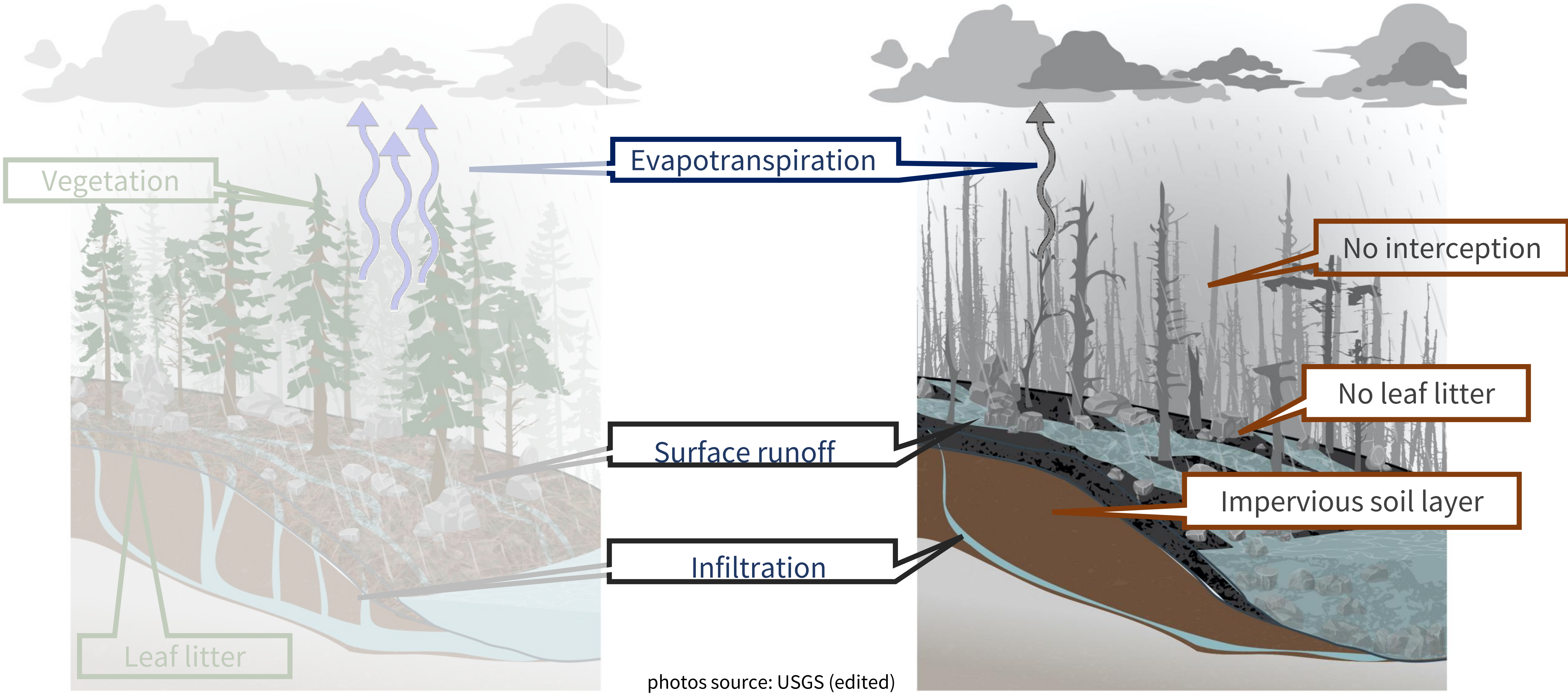
Forests: a precipitation sponge



photos source: USGS (edited)

Wildfires and the hydrological cycle

Forests: a precipitation sponge



photos source: USGS (edited)

What are we looking for?

We need a metric to determine the amount of water that runs off a basin:

$$\text{Runoff Coefficient} = \frac{\text{Runoff volume (m}^3\text{ per water year*)}}{\text{Precipitation volume (m}^3\text{ per water year)}}$$

*Water year is defined per watershed as the months around the climatological month with the highest FWI index

Changes in the runoff coefficient

Changes in runoff coefficient are highly affected from various climatological parameters.

- Train regression model to predict the runoff coefficient for years around a wildfire.

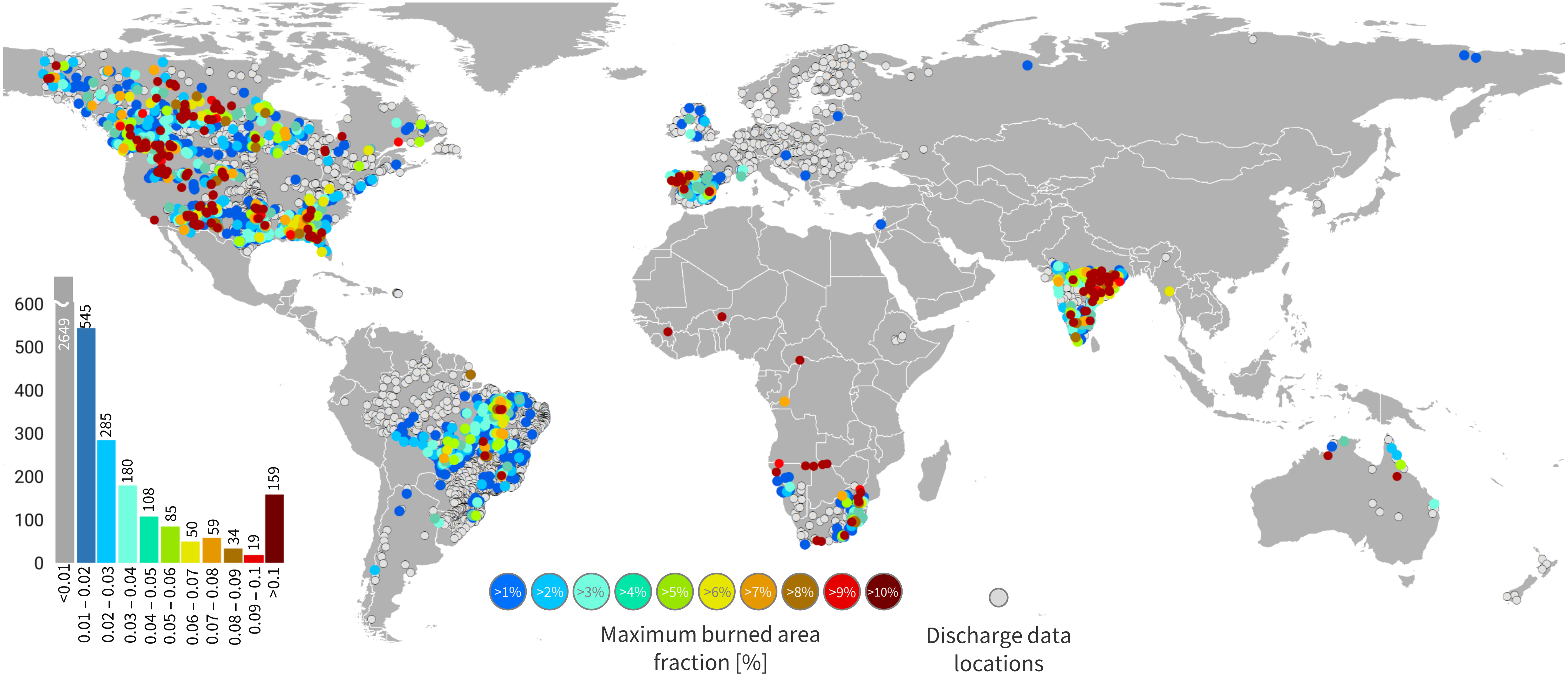
$$\textit{Runoff Coeff} = f(PR, TEMP, PET)$$

- Use the regression model to estimate the runoff coefficient for burn affected years.

$$\textit{Runoff Coeff} = f(PR, TEMP, PET)$$

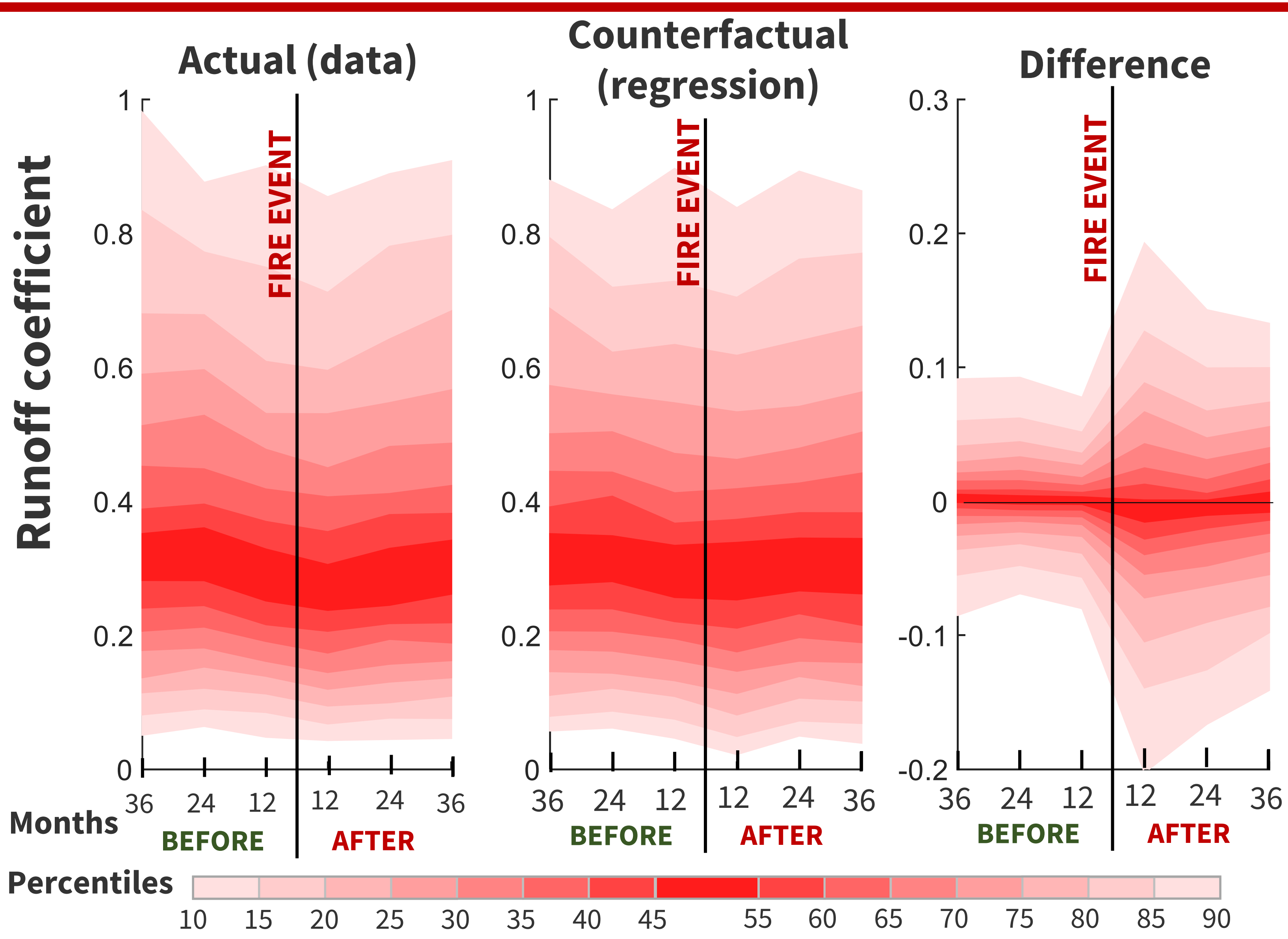
Counterfactual Runoff coefficient

Maximum burned area fraction for each basin [%]

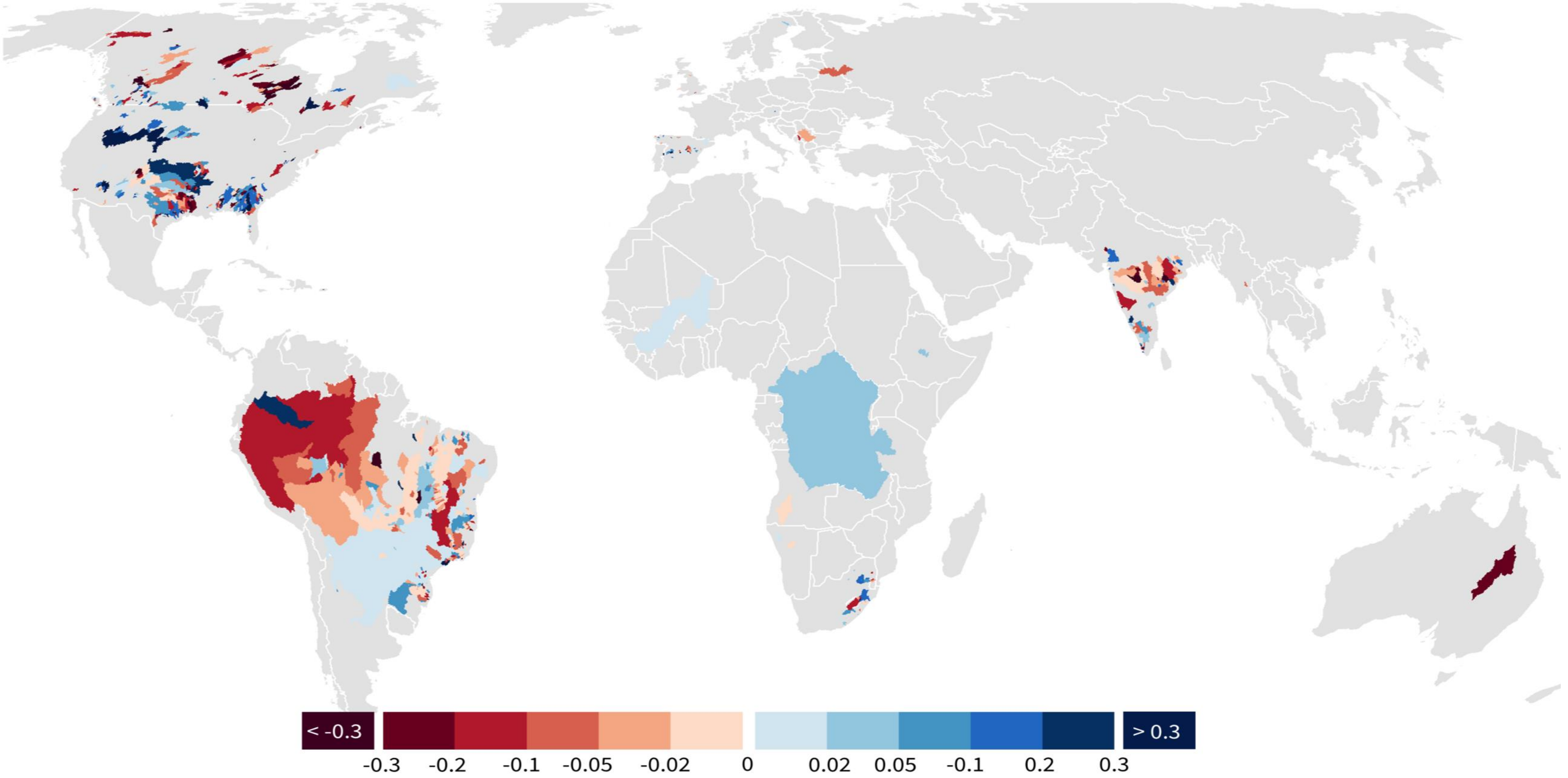


Upstream burned area fraction for each river discharge location.

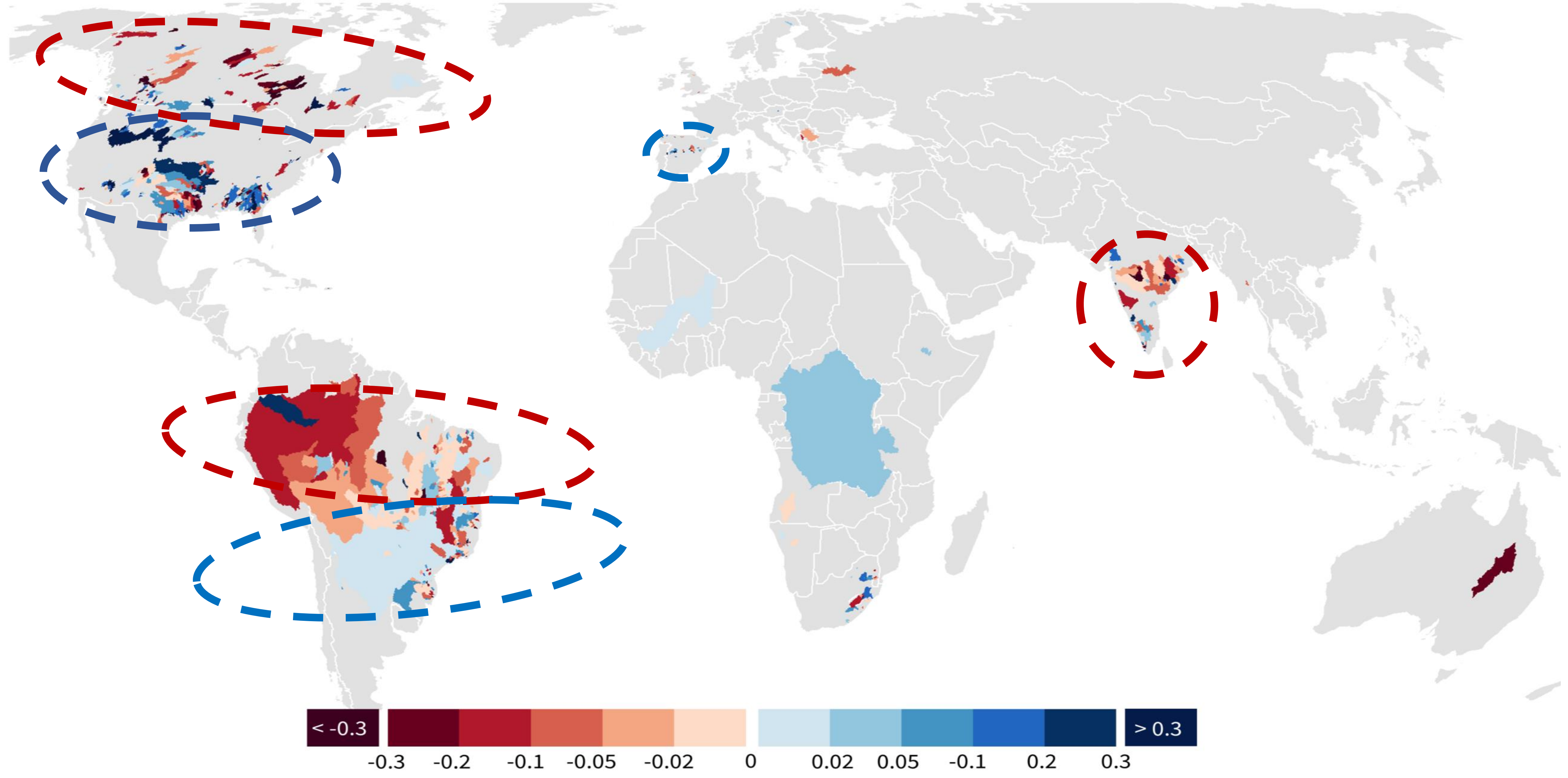
Runoff coefficient changes after a wildfire - Global



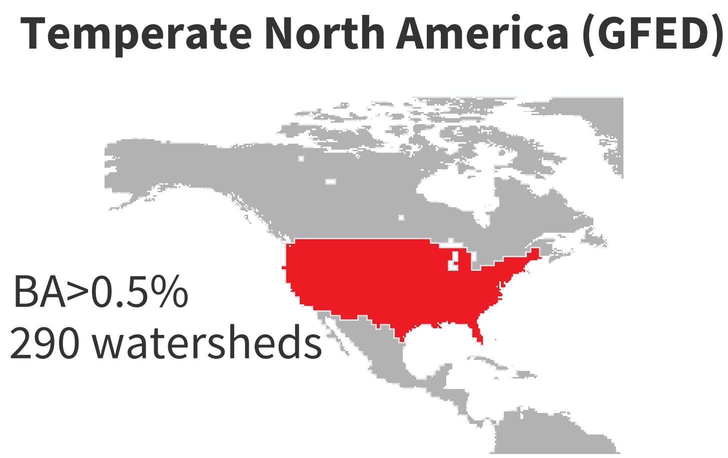
Runoff coefficient change 1st year after a fire

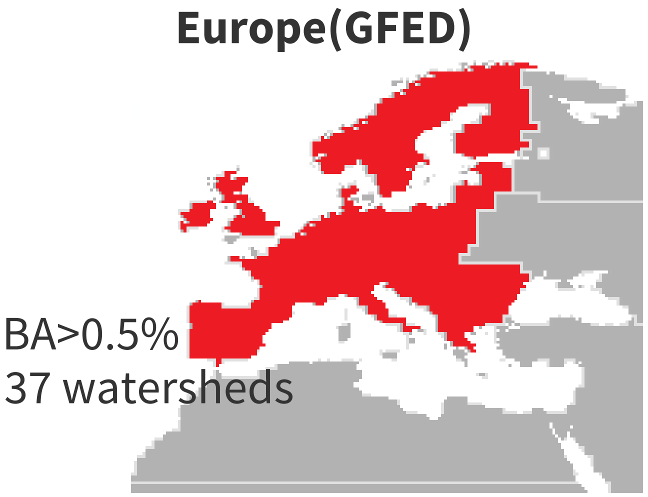


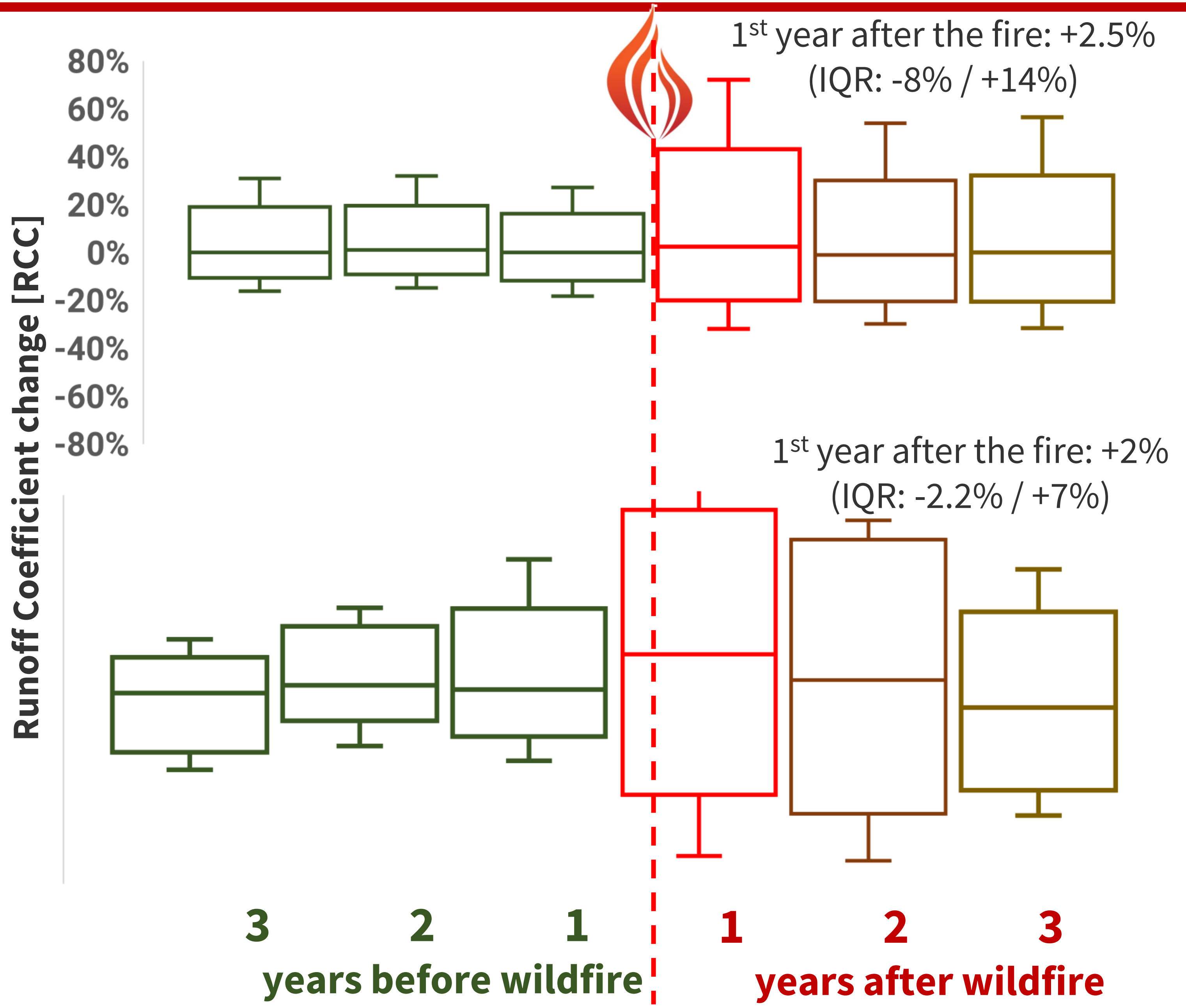
Runoff coefficient change 1st year after a fire



Detectable changes – annual basis | BA>0.5%

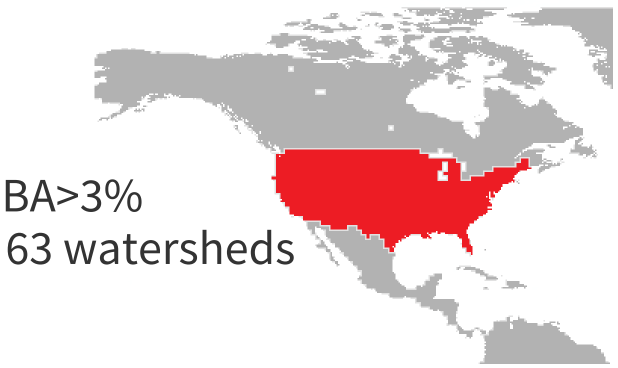




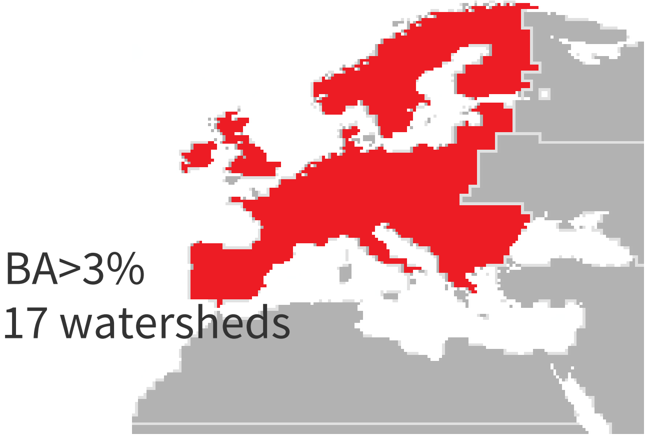


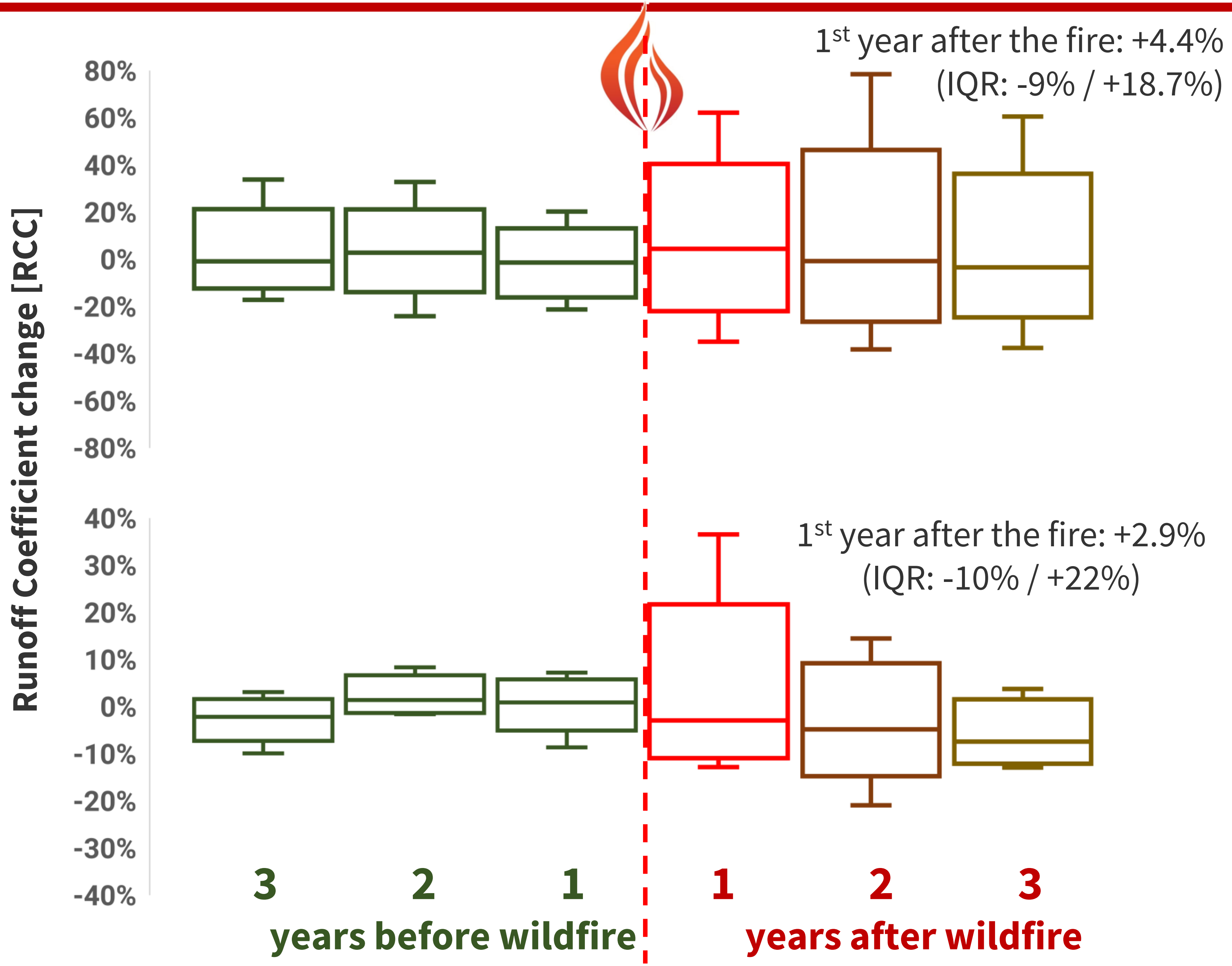
Detectable changes – annual basis | BA>3%

Temperate North America (GFED)

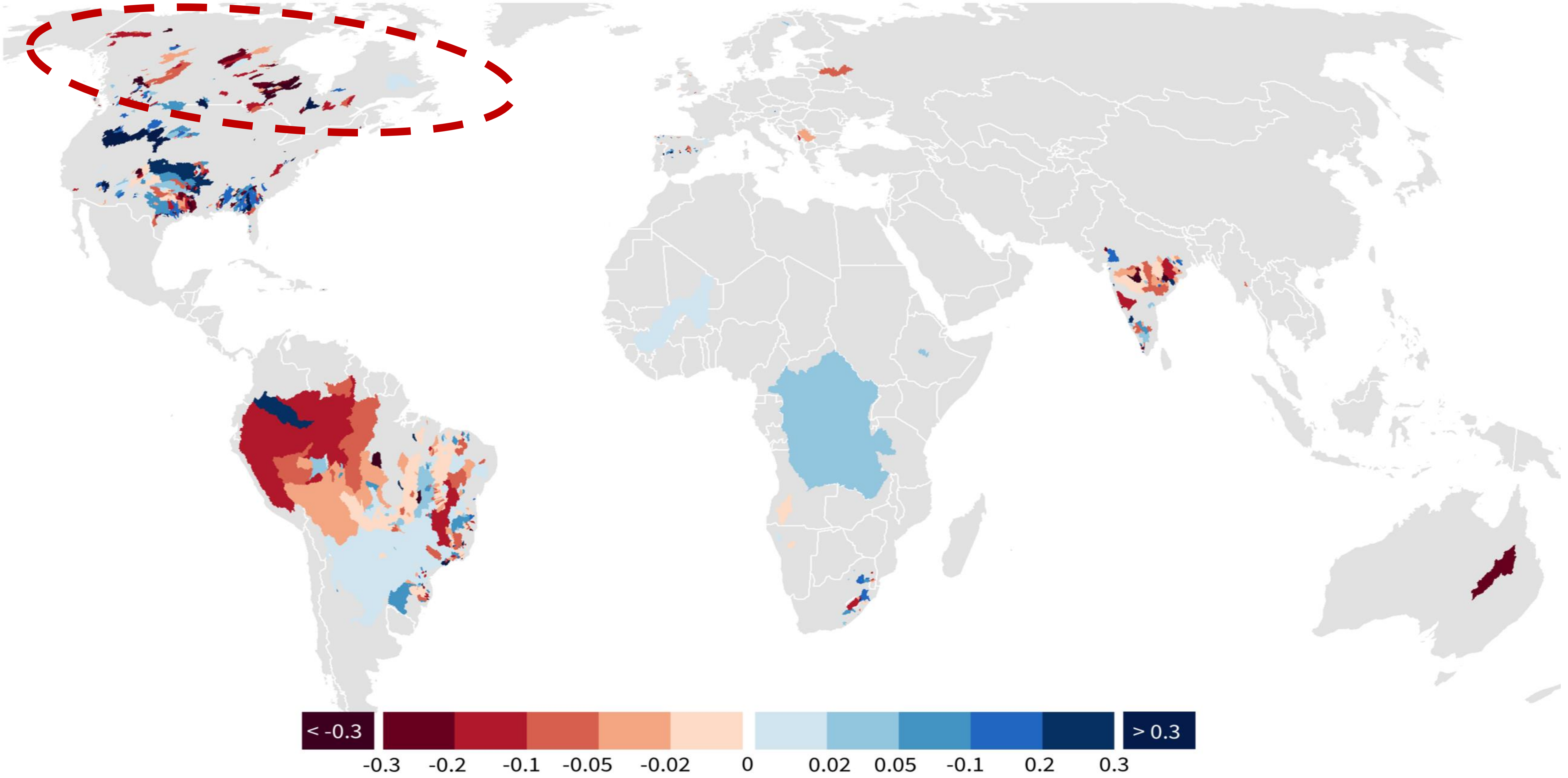


Europe(GFED)



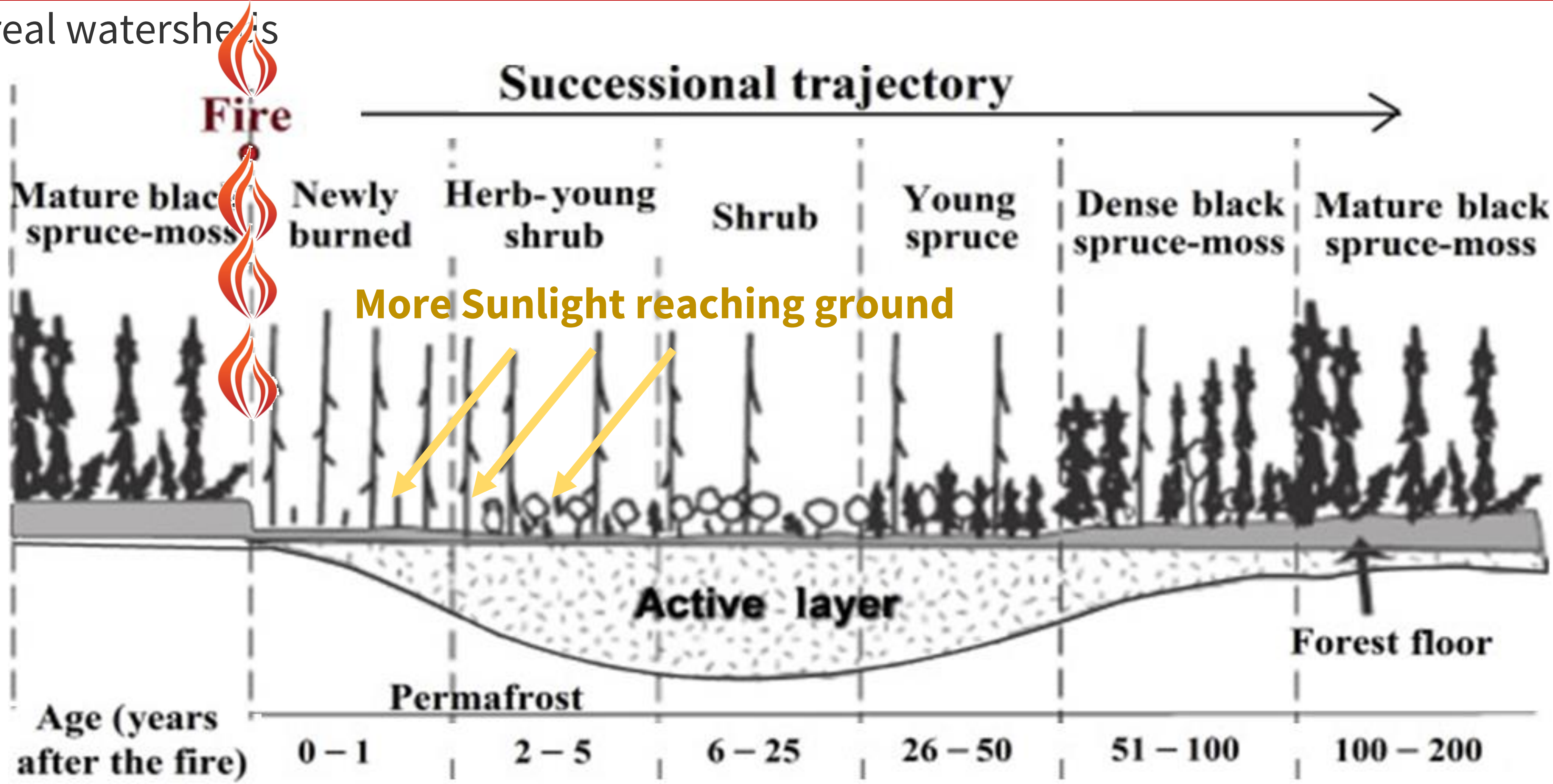


Boreal regions



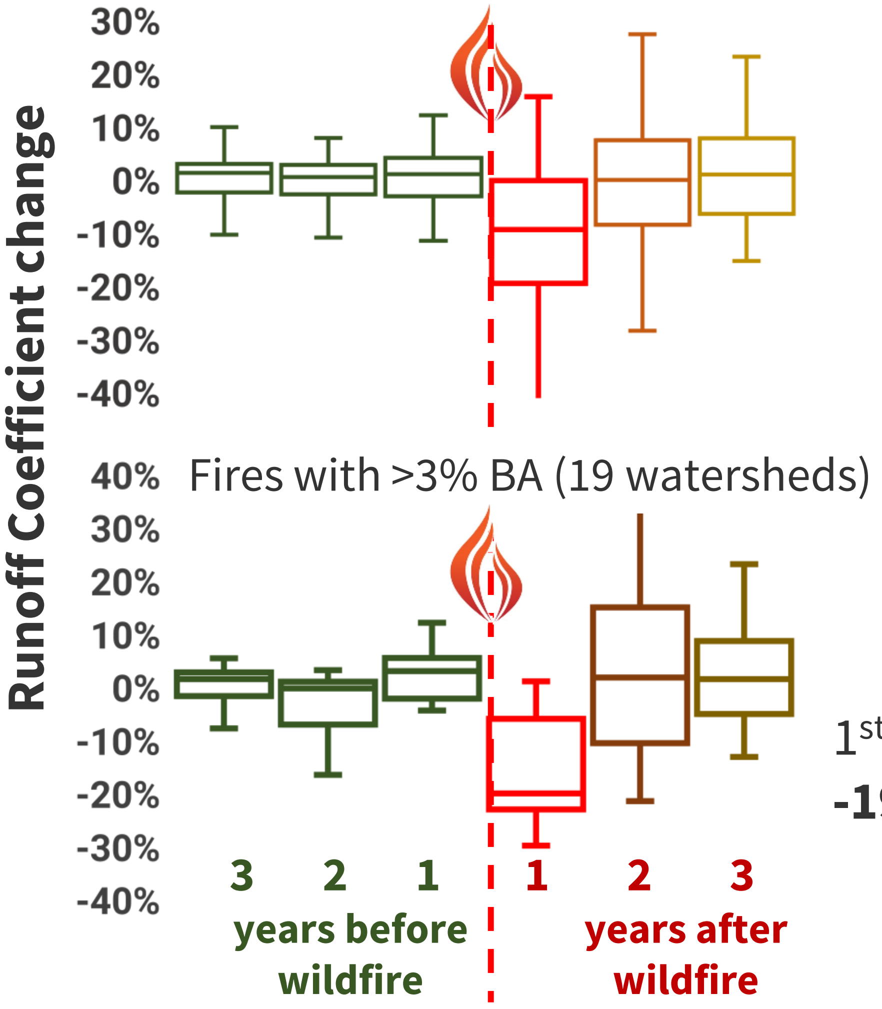
Boreal regions

Boreal watersheds



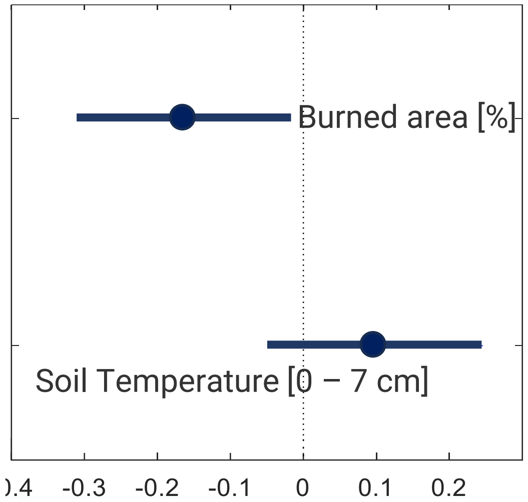
Li, X.-Y. *et al.* Influences of forest fires on the permafrost environment: A review. *Adv. Clim. Chang. Res.* **12**, 48–65 (2021).

Boreal regions



1st year after the fire:
-9.2% (IQR: -1.3% / -18.3%)

1st year after the fire:
-19.8% (IQR: -7.6% / -22.1%)



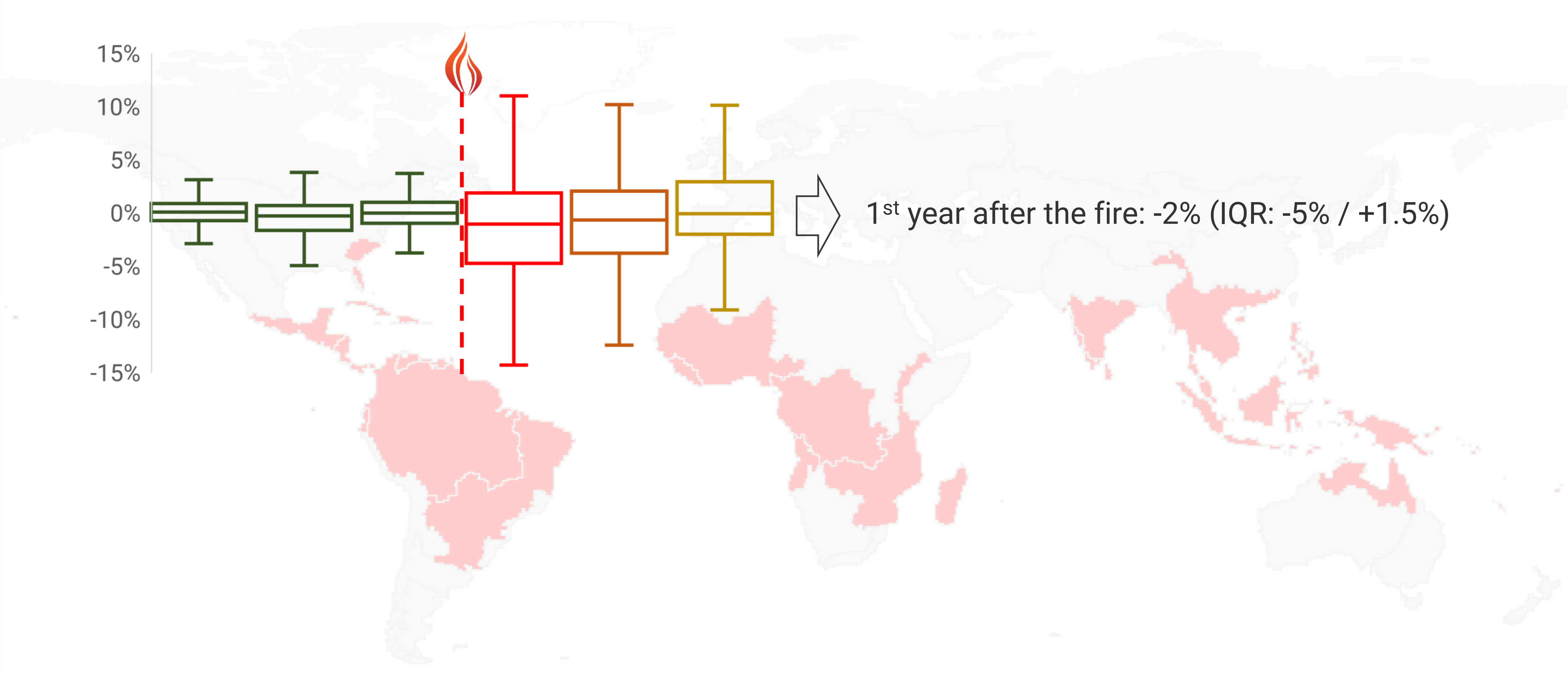
Main effects in the 1st year after wildfire

BA: significant negative effect (Higher BA, lower change)

SoilT: positive effect (higher temps – less negative RCCs) consistent with literature.

Tropics and Sub-tropics

Tropics and Sub-tropics



1st year after the fire: -2% (IQR: -5% / +1.5%)

Conclusions

Differential effects of wildfires on river flows:

- Positive changes in mid-latitudes and dry regions
- Strong negative changes in boreal regions
- Negative changes in tropics/subtropics

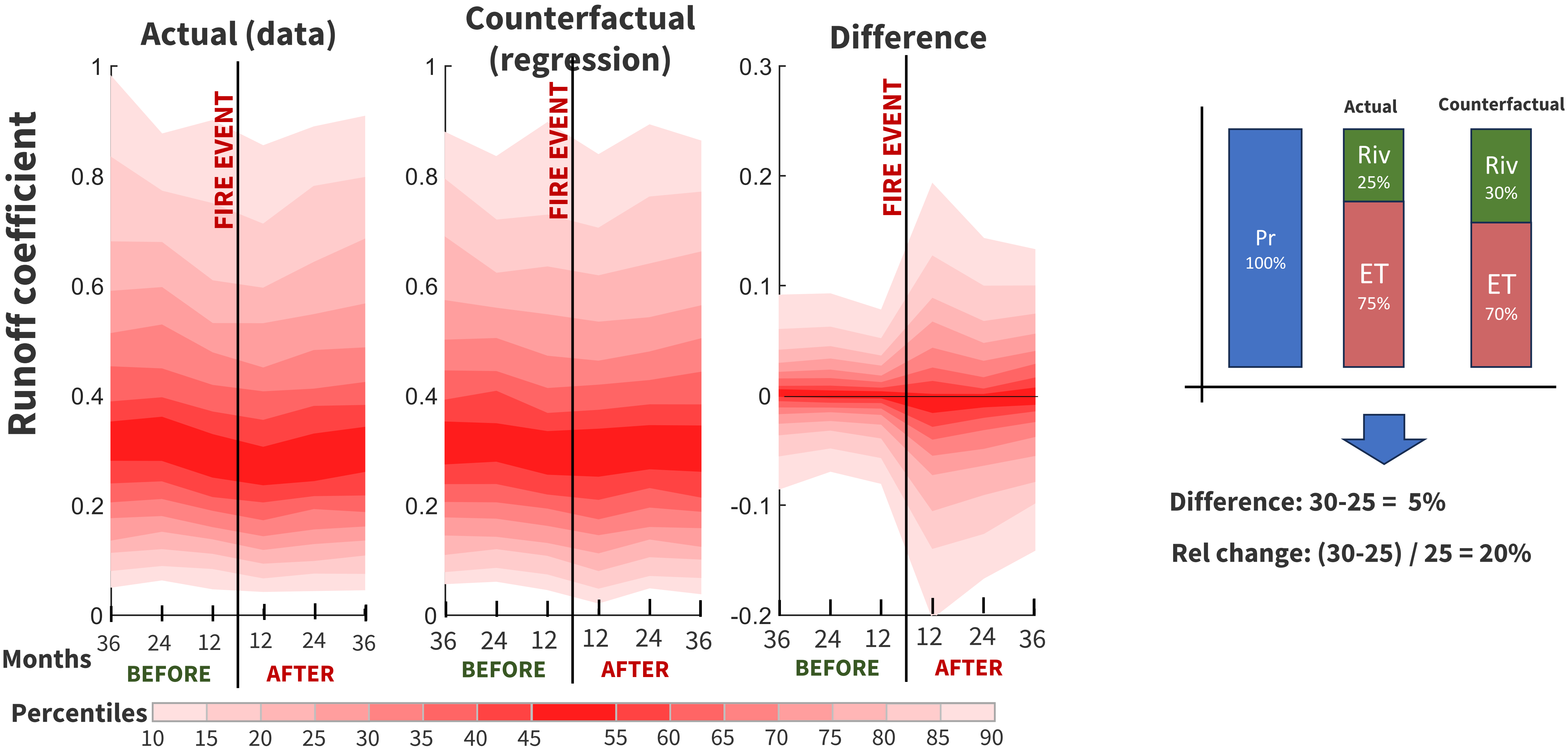
Next:

- More analysis is needed for the tropics/subtropics

Thank you!

Questions?

Runoff coefficient changes after a wildfire - Global



Difference: 30-25 = 5%

Rel change: (30-25) / 25 = 20%

Literature?

US: Lower Colorado region:

"Wildland fires increased annual river flow most in the semi-arid Lower Colorado region, in spite of frequent droughts in this region." **Hallema, D. W. *et al. Nat. Commun.* 9, 1–8 (2018).**

US: Western United States:

"Among basins where >20% of forest burned, postfire streamflow is significantly enhanced by an average of approximately 30% for 6 y". **Williams, A. P. *et al. Proc. Natl. Acad. Sci. U. S. A.* 119, e2114069119 (2022).**

Europe and US:

experimental analyses conducted both in Europe and in the United States indicate that the annual peak discharge in post-fire conditions can increase by a factor generally ranging from 1.2 to 6.5 times…" Leopardi, M., & Scorzini, A. R. (2015). ***iForest-Biogeosciences and Forestry, 8(3), 302.***

The Idea

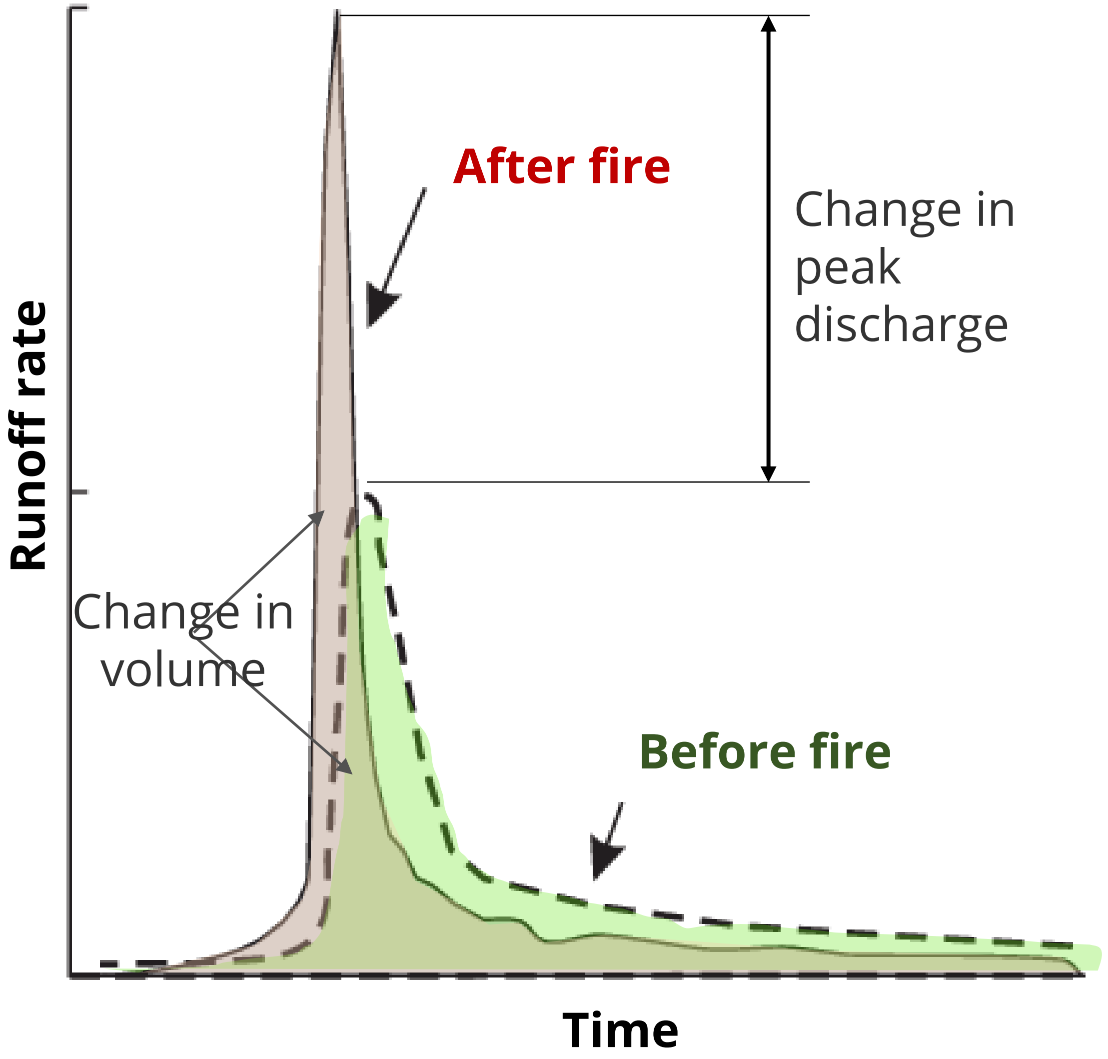
Hydrological processes are affected in various ways:

Runoff volumes increase due to:
- Diminished canopy interception
- Diminished canopy transpiration
- Reduced water infiltration in the soil

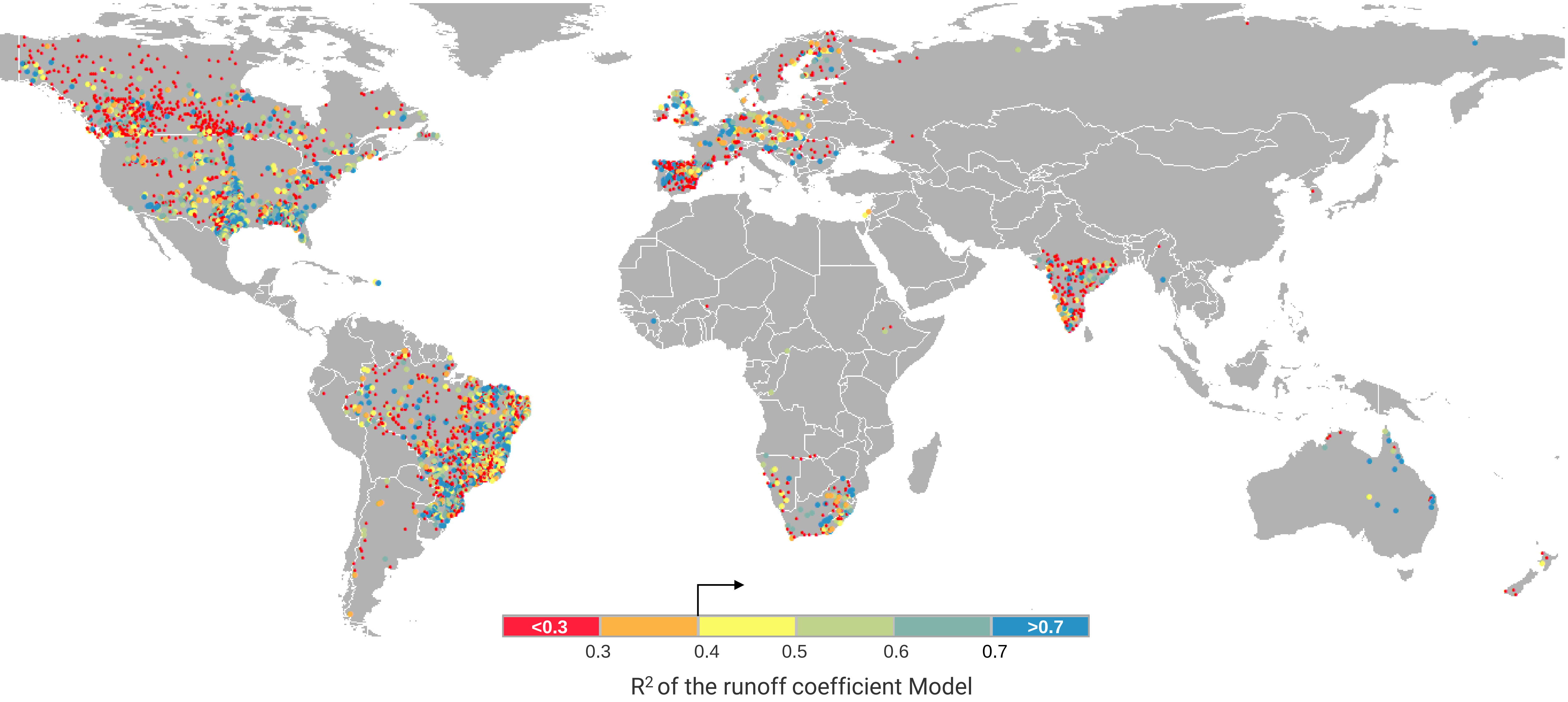
Sharper hydrographs:
- Runoff speeds increase

But also:

Frozen soils unfreeze
- The hydrologically active layer thickness increases

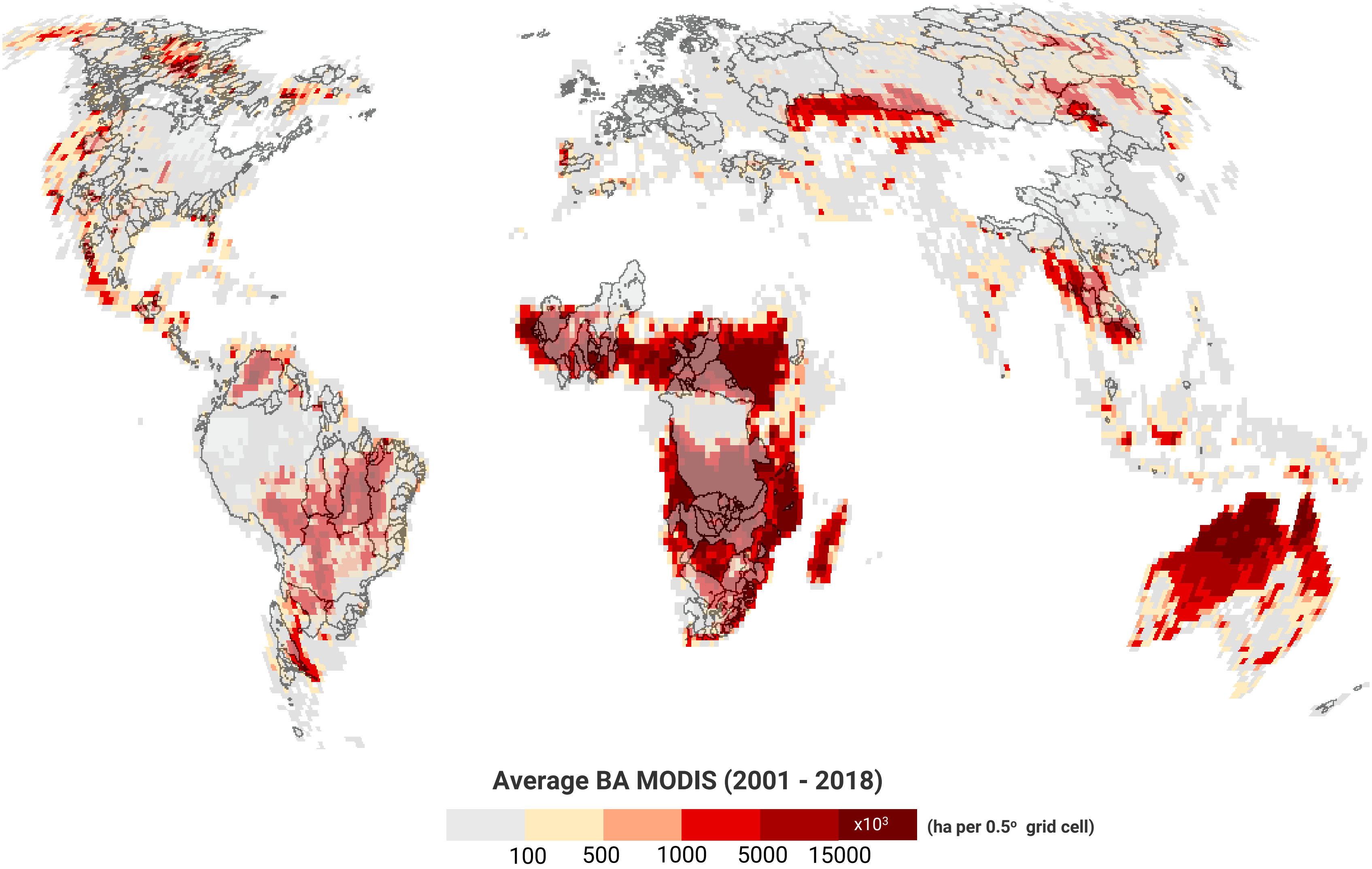


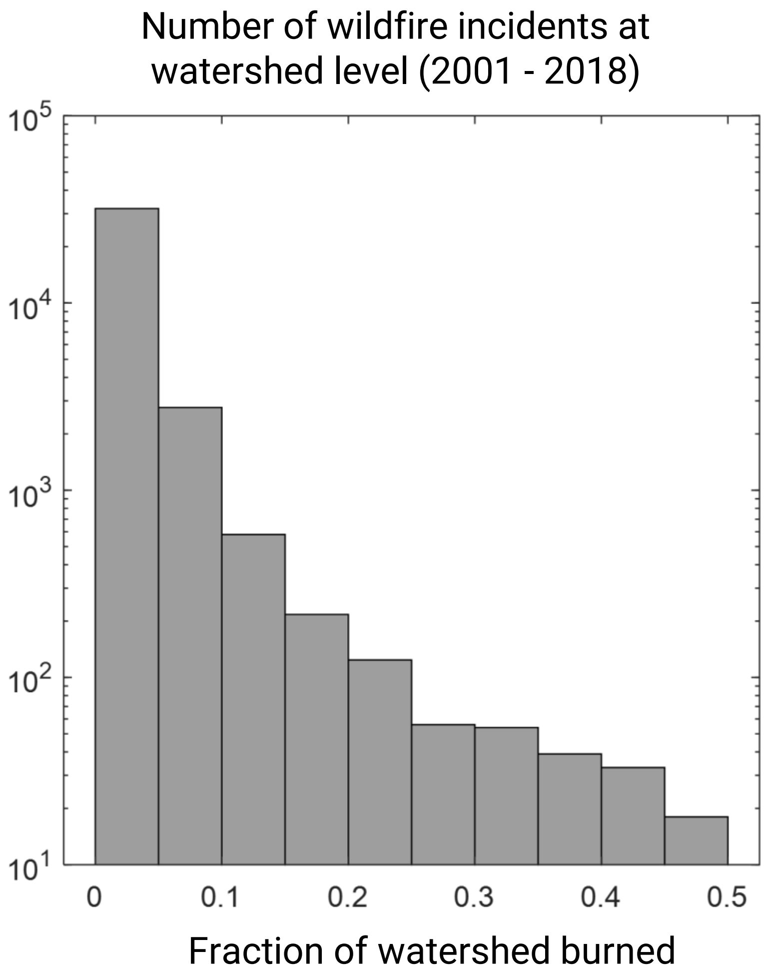
R^2 of the regression model



Data – MODIS

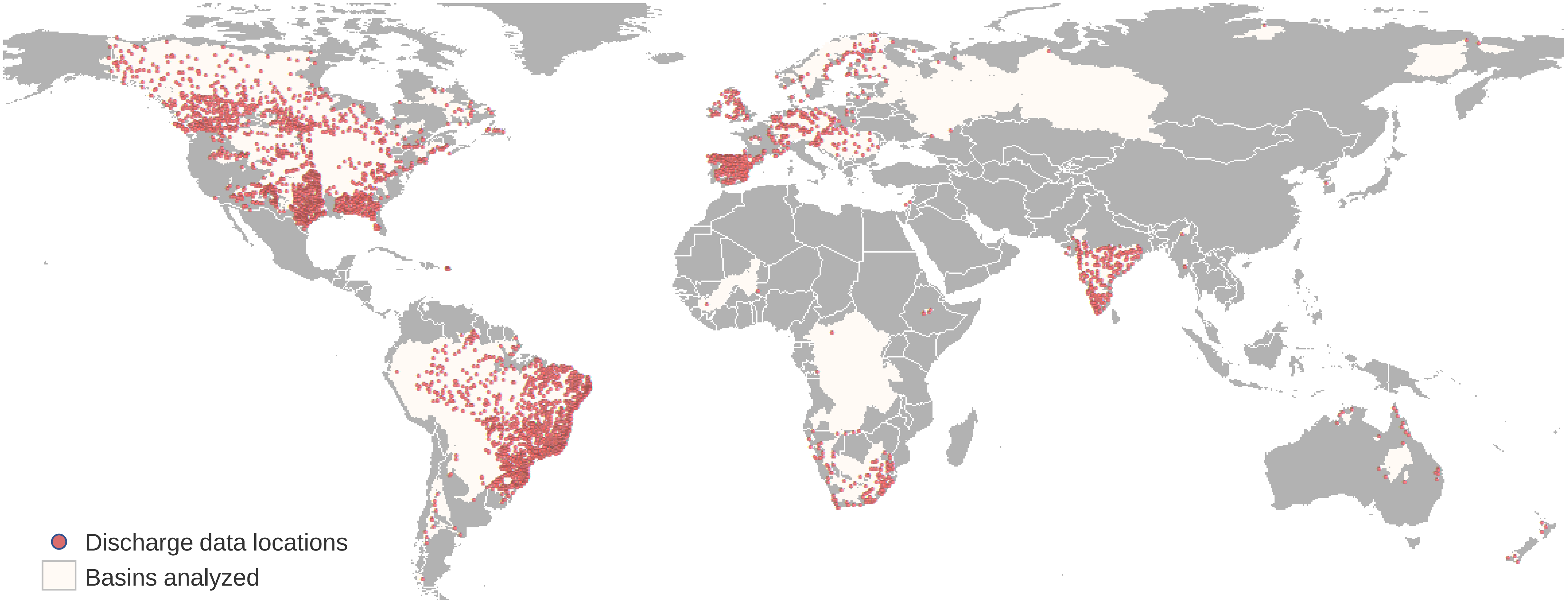
We started exploring the burned area fraction



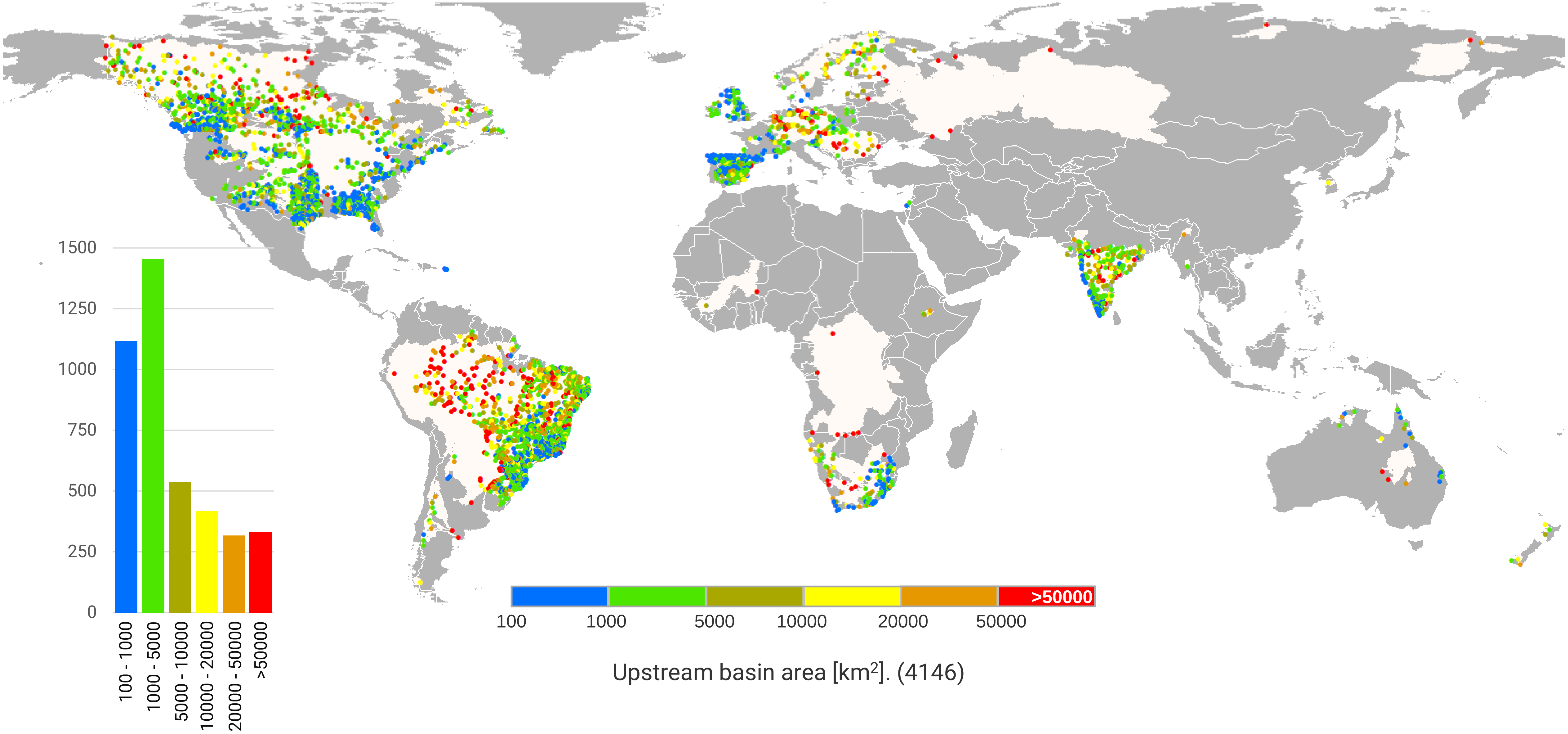


Data– River discharge

River discharge locations with at least 10 years of available data between 2001 – 2018



Upstream basin area [Km2]



Upstream basin area [km^2]. (4146)

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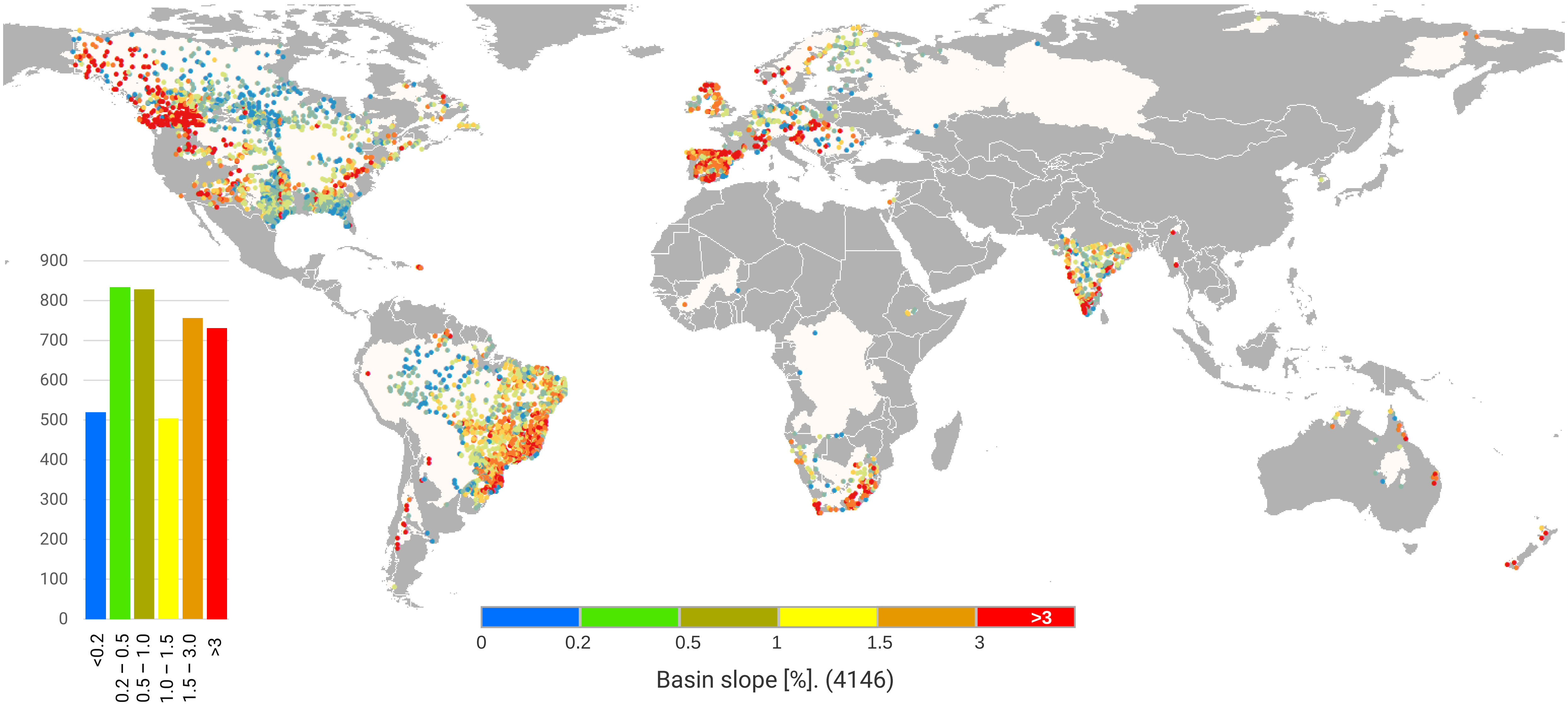
Basin slope [%]



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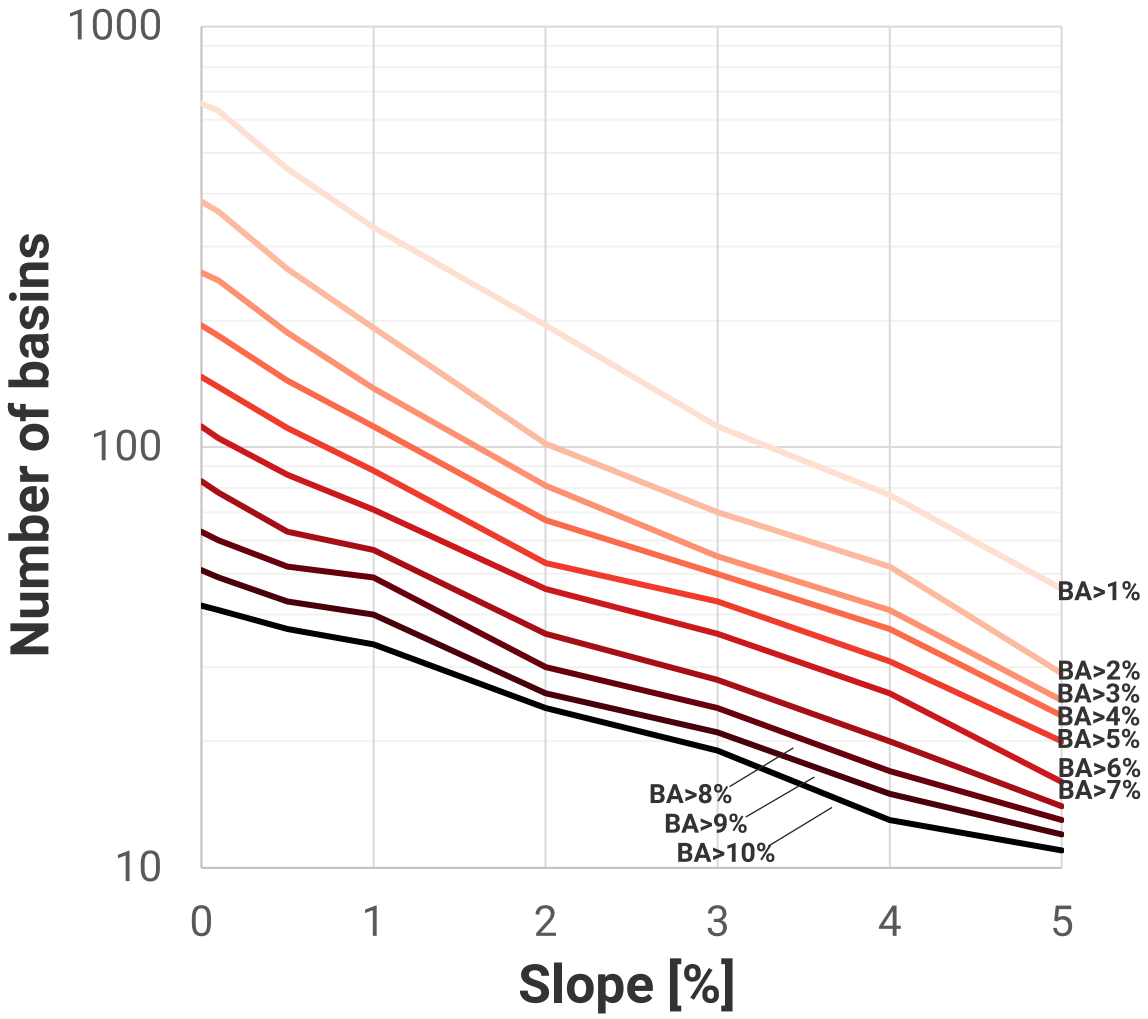
Basin slope [%] – Basin BA [%]



	Average basin slope [%]							
Burned Area [%]	**0**	**0.1**	**0.5**	**1**	**2**	**3**	**4**	**5**
1	656	630	459	333	195	112	77	46
2	384	363	265	192	102	70	52	29
3	260	249	187	138	81	55	41	25
4	195	184	144	112	67	50	37	23
5	147	139	111	88	53	43	31	20
6	112	105	86	71	46	36	26	16
7	83	78	63	57	36	28	20	14
8	63	60	52	49	30	24	17	13
9	51	49	43	40	26	21	15	12
##	42	41	37	34	24	19	13	11

Hydrobelts – Climatic regions – whole watersheds

Runoff coefficient estimated on actual data, counterfactual data and their difference