Regional to Global-Scale Fire and Fire Emissions Model Projections

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Image: NASA GSFC
July 2002

- There is growing interest in making projections of future fire

  –meteorological risk

  –burned area

  –carbon emissions

- Some Earth System models simulate fire as part of the climate system

- Simulated climate can also be used in a fire-vegetation model

Invited research article

Historical and future fire occurrence (1850 to 2100) simulated in CMIP5 Earth System Models

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ARTICLE INFO

ABSTRACT

Earth System Models (ESMs) have recently integrated fire processes in their vegetation model components to account for fire as an important disturbance process for vegetation dynamics and agent in the land carbon cycle. The present study analyses the performance of ESMs that participated in the 5th Coupled Model Intercomparison Project (CMIP5) in simulating historical and future fire occurrence. The global present day (1981 to 2005) burned area simulated in the analysed ESMs ranges between 149 and 208Mha, which is substantially lower than the most recent observation based estimate of 399Mha (GFEDv4s averaged over the time period 1997 to 2015). Simulated global fire carbon emissions, however, are with 2.0PgC/year to 2.7PgC/year on the higher end compared to the GFEDv4s estimate of 2.2PgC/year. Regionally, largest differences are found for Africa. Over the historical period (1850 to 2005) changes in simulated fire carbon emissions range between an increase of +43% and a decrease of −35%. For the future (2005 to 2100) we analysed the CMIP5 simulations following the representative concentration pathways (RCPs) 26, 45, and 85, for which the strongest changes in global fire carbon emissions simulated in the single ESMs amount to +8%, +52% and +58%, respectively. Overall, however, there is little agreement between the single ESMs on how fire occurrence changed over the past or will change in the future. Furthermore, contrasting simulated changes in fire carbon emissions and changes in annual mean precipitation shows no emergent pattern among the different analysed ESMs on the regional or global scale. This indicates differences in the single fire model representations that should be subject of upcoming fire model intercomparison studies. The increasing information derived from observational datasets (charcoal, ice-cores, satellite, inventories) will help to further constrain the trajectories of fire models.

1. Introduction

Fire is a fundamental process in the Earth System (Bowman et al., 2009). Fires impact vegetation dynamics (Bond et al., 2004), biogeochemical cycles (Bond-Lamberty et al., 2007), biogeophysical processes (Liu and Randerson, 2008) and physical and chemical processes in the atmosphere (Ward et al., 2012). Fire is the most important disturbance process for vegetation and is currently estimated to emit about 2 PgC per year into the atmosphere (van der Werf et al., 2010). Fire occurrence depends on climate conditions. If climate change results in more frequent fires this would result in a net transfer of carbon from the land into the atmosphere, contributing to the positive climate-carbon cycle feedback

vegetation model components of Earth System Models (ESMs) and a quantitative assessment of the performance of these models reproducing spatial and temporal variations in fire occurrence on regional and global scale is still lacking (Hantson et al., 2016). Our aim in this study is to analyse ESMs participating in CMIP5 in order to: (i) evaluate simulated present day burned area using observed burned area data and (ii) quantify the difference in the simulated trend in burned area and fire carbon emissions in the different ESMs for the historical and future time period. Differences in simulated burned area and fire carbon emissions in the different ESMs are expected as these models have been shown to differ significantly in terms of e.g. simulated meteorology (Kumar et al., 2013), carbon dynamics (Anav et al., 2013, Friedlingstein et al., 2014) and vegetation distri-
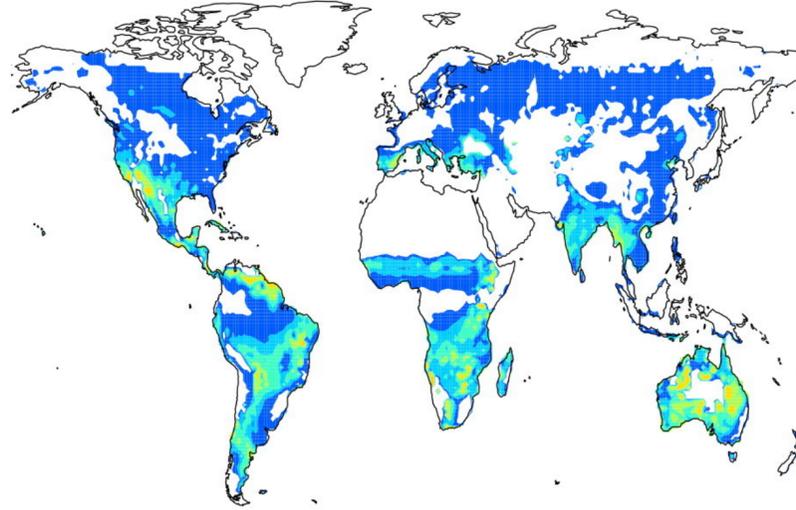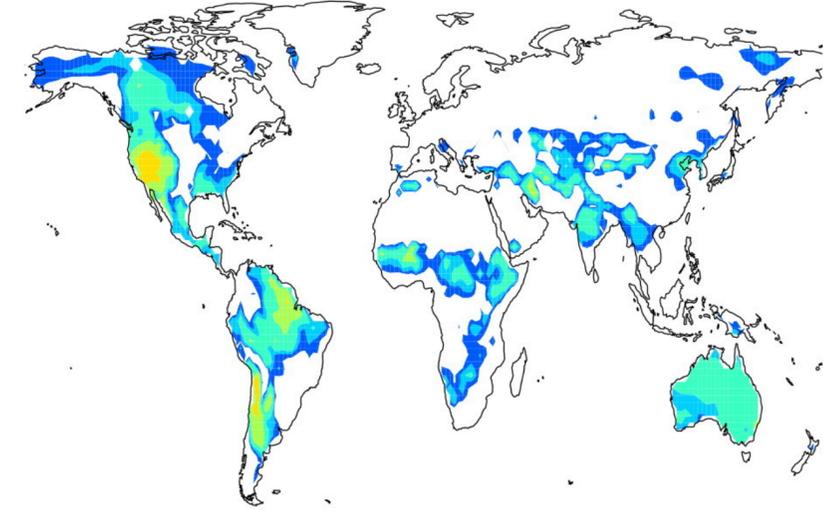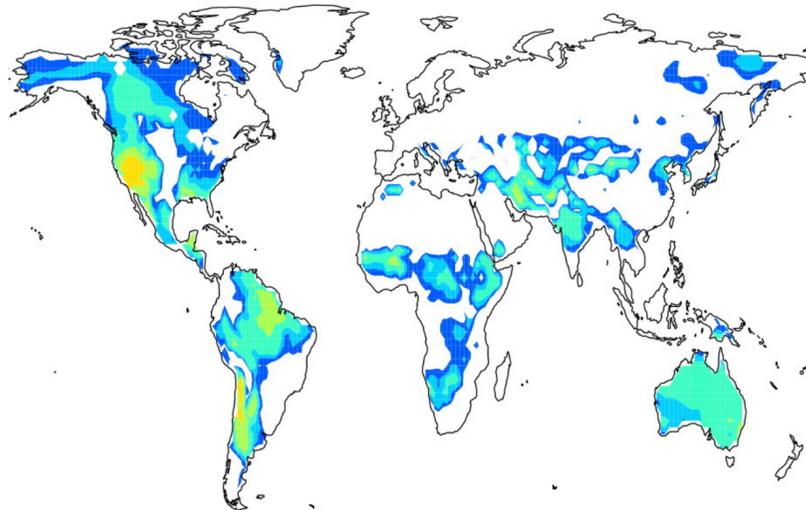
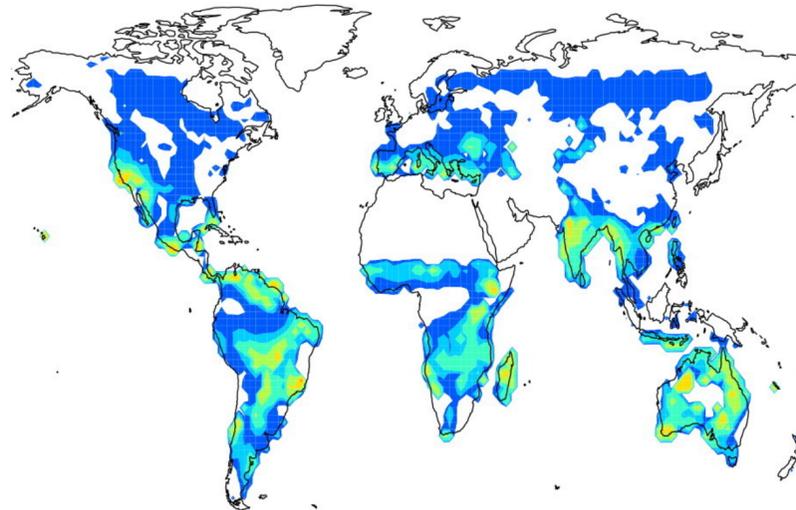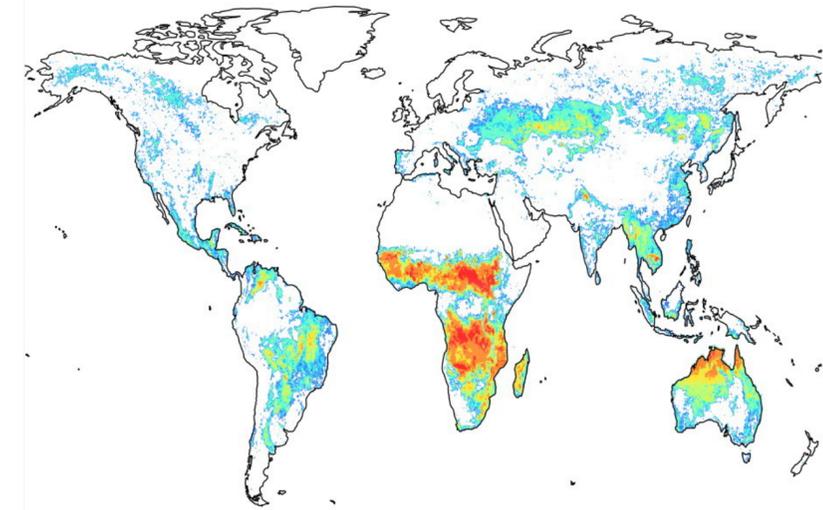# 1981-2005 burned area from earth system models (ESMs)

CESM1-BGC
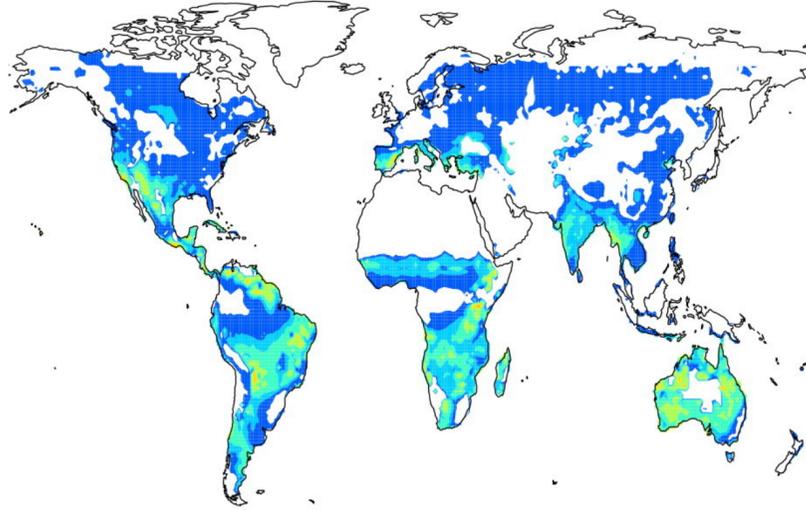
CCSM

MPI-ESM-MR

MPI-ESM-LR

NorESM1

GFEDv4s

Mean annual burned area

0.0   0.5   1.0   2.0   5.0   10.0   20.0   50.0   100.0   %

Future projections using climate models' fire schemes
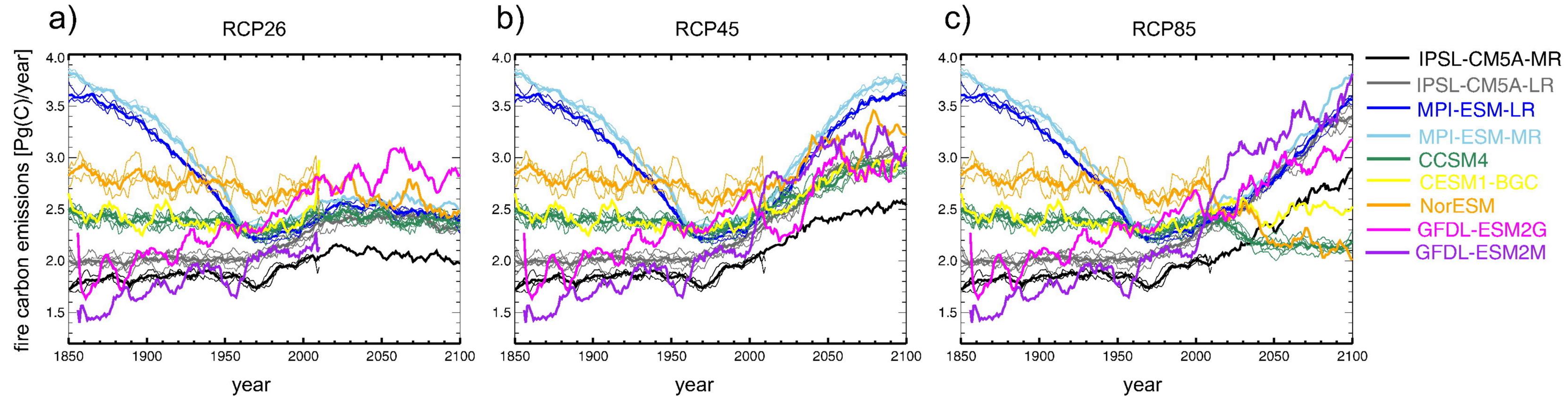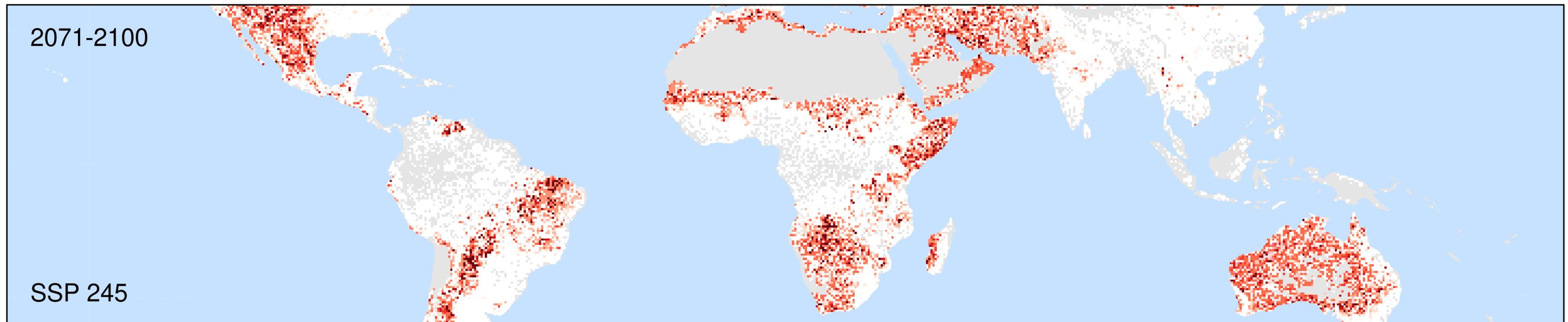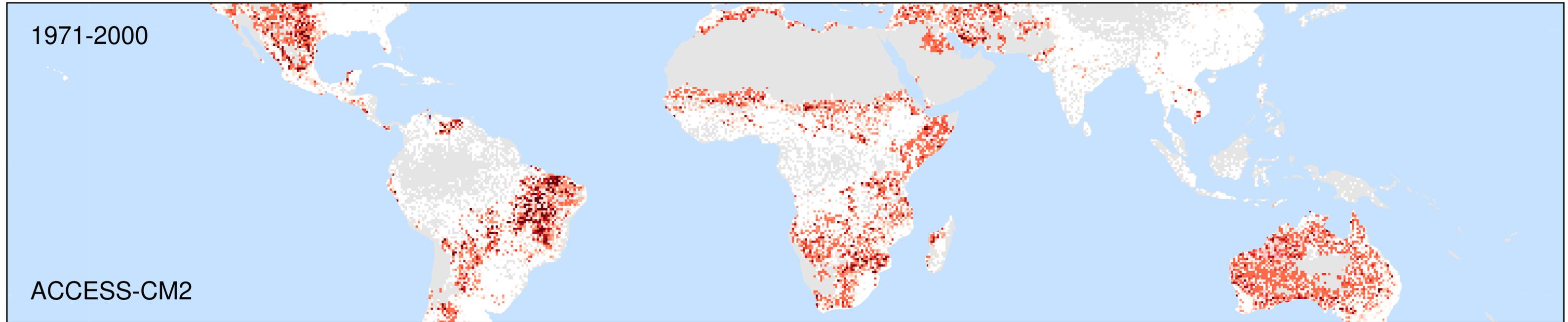
a) RCP26

b) RCP45

c) RCP85

fire carbon emissions [Pg(C)/year]

year

IPSL-CM5A-MR
IPSL-CM5A-LR
MPI-ESM-LR
MPI-ESM-MR
CCSM4
CESM1-BGC
NorESM
GFDL-ESM2G
GFDL-ESM2M

Kloster and Lasslop, 2017

ESM climate → LPJ-LMfire vegetation-fire model

1971-2000

ACCESS-CM2

2071-2100

SSP 245

no fire

| 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 |

mean annual gridcell burned area (%)

Koch and Kaplan, 2022

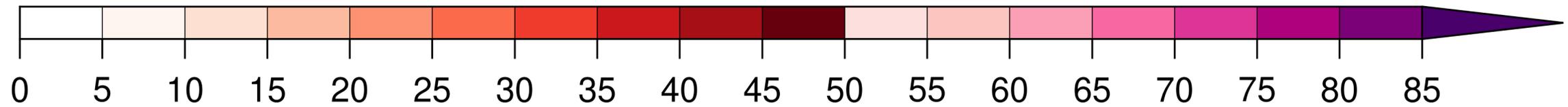# ESM climate → LPJ-LMfire vegetation-fire model

1971-2000

BCC-CSM2-MR

2071-2100

SSP 245

no fire

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85

mean annual gridcell burned area (%)

Koch and Kaplan, 2022
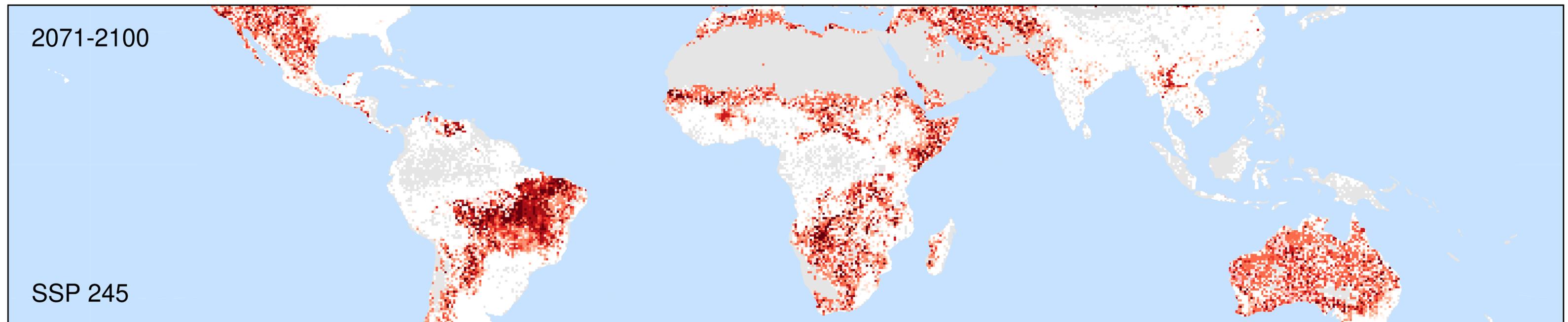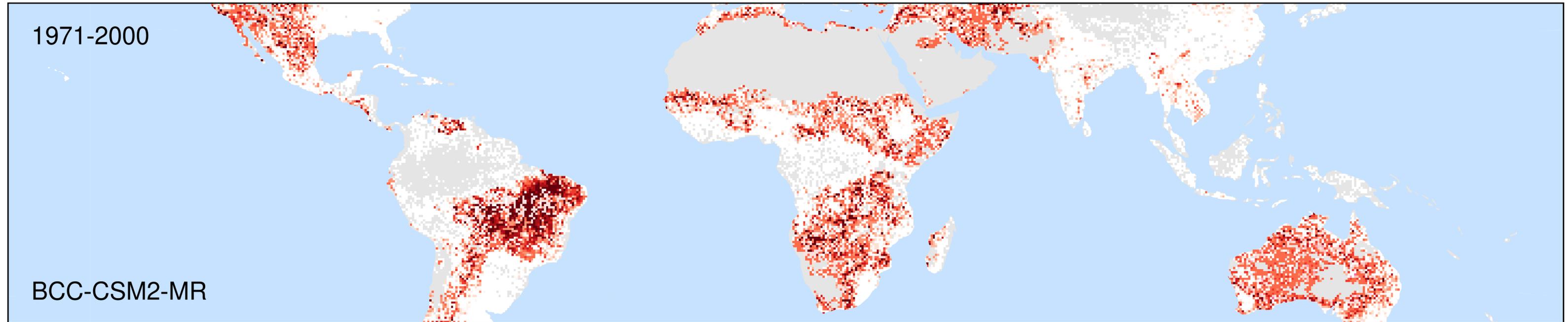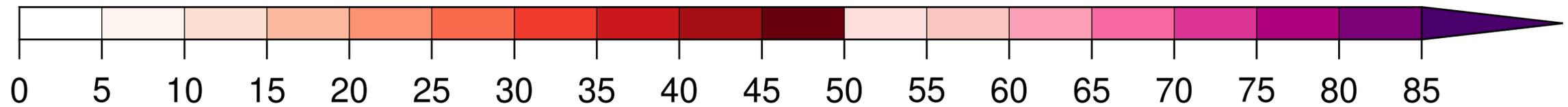
Tropical fire carbon emissions (ESM → LPJ-LMfire)

SSP 126

Koch and Kaplan, 2022

Tropical fire carbon emissions (ESM → LPJ-LMfire)

SSP 245

37°N - 37°S

Legend:
- BCC–CSM2–MR
- FGOALS–g3
- CanESM5
- MIROC6
- INM–CM4–8
- INM–CM5–0
- MRI–ESM2–0
- ACCESS–ESM1–5
- AWI–CM–1–1–MR
- IPSL–CM6A–LR
- EC–Earth3–Veg
- MPI–ESM1–2–HR
- ACCESS–CM2

y-axis: fire carbon emissions (Pg C yr^{-1})

x-axis: year

Koch and Kaplan, 2022
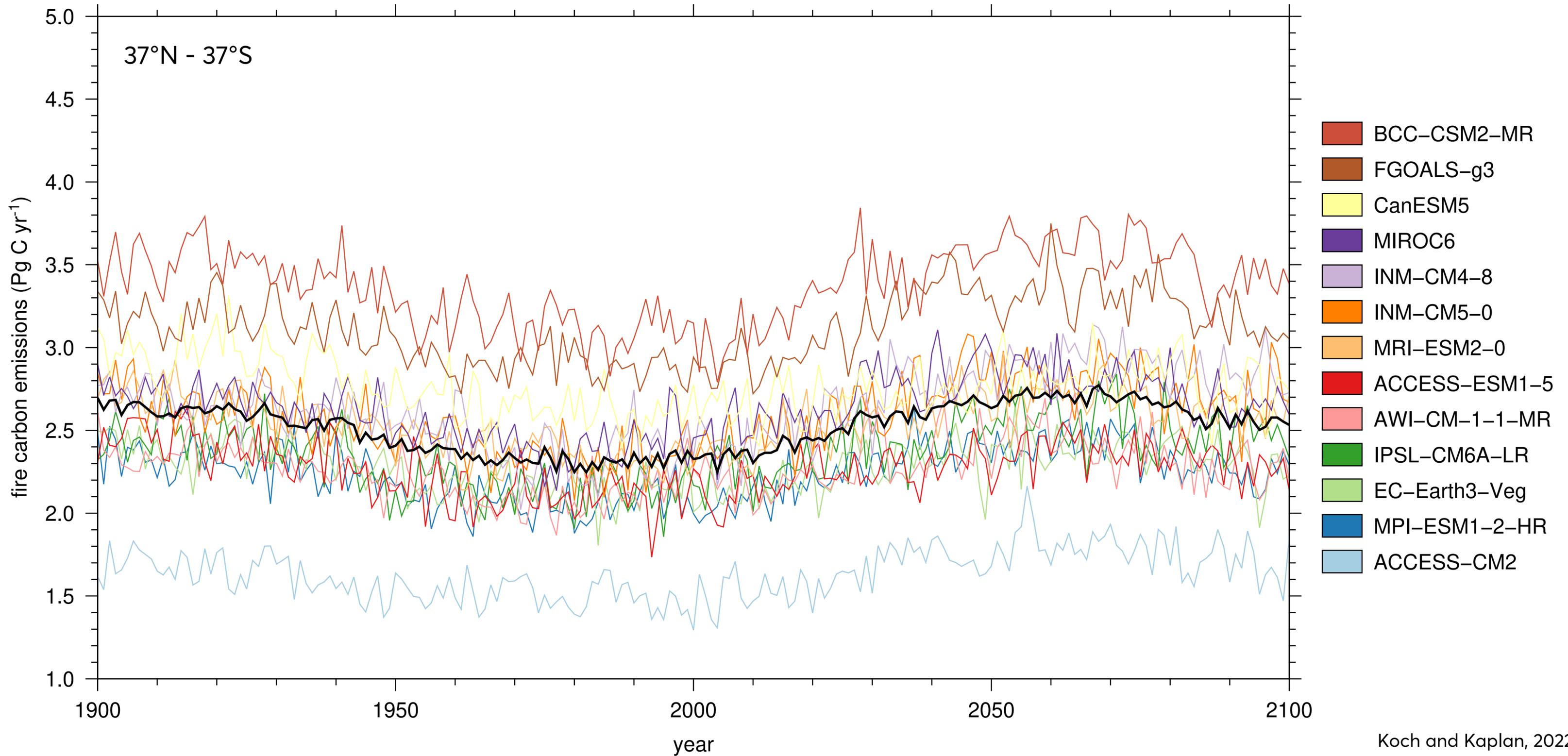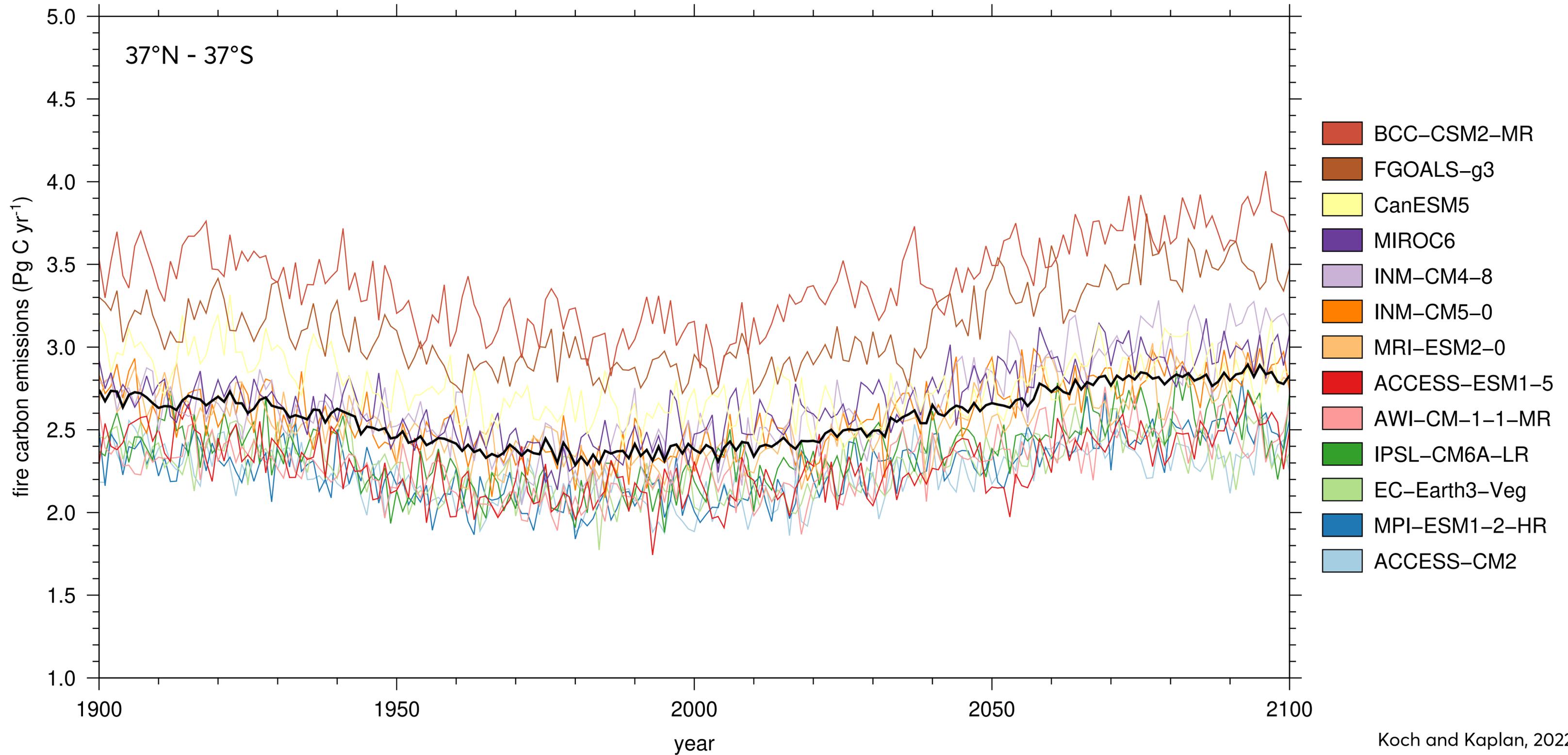
Tropical fire carbon emissions (ESM → LPJ-LMfire)

SSP 370

Koch and Kaplan, 2022

Tropical fire carbon emissions (ESM → LPJ-LMfire)

SSP 585

37°N - 37°S

Legend:
- BCC–CSM2–MR
- FGOALS–g3
- CanESM5
- MIROC6
- INM–CM4–8
- INM–CM5–0
- MRI–ESM2–0
- ACCESS–ESM1–5
- AWI–CM–1–1–MR
- IPSL–CM6A–LR
- EC–Earth3–Veg
- MPI–ESM1–2–HR
- ACCESS–CM2

y-axis: fire carbon emissions (Pg C yr^{-1})

x-axis: year

Koch and Kaplan, 2022
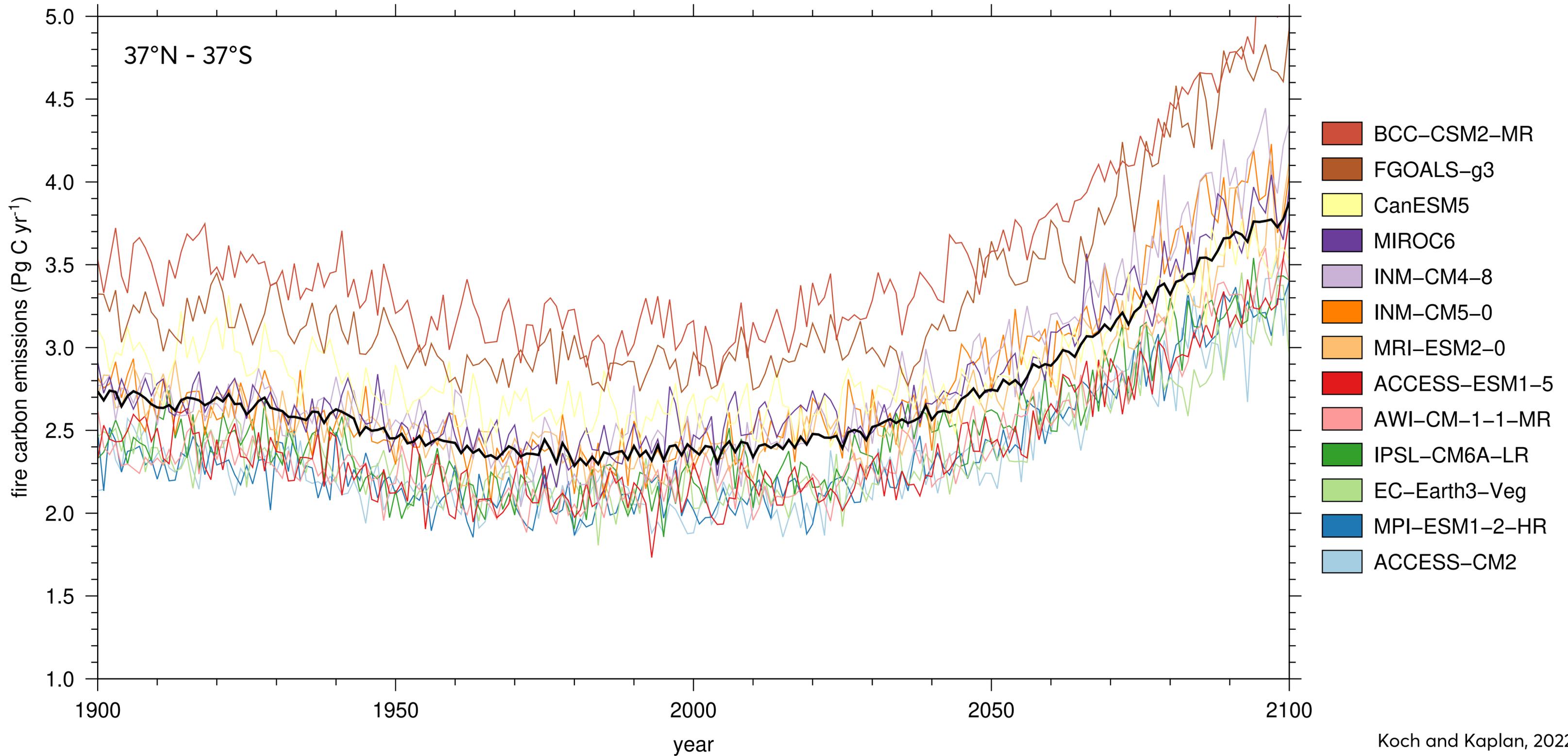
- Simulated meteorology - climate models are wildly different even for present-day

- Fuels and their structure are not well evaluated

- Spatial resolution and landscape heterogeneity are poorly represented

- **Anthropogenic fire**: Land management, fire use, and efforts/policies to mitigate fire is largely missing.

New Territories, Hong Kong

Global Fire Use Survey: Project Information

People around the world – from subsistence farmers and Indigenous peoples to state agencies, non-governmental organisations, and commercial foresters and farmers—use and control fire in different ways for different purposes. These diverse cultural practices now shape fire regimes across the planet, yet they remain poorly understood at global scale, leading to inaccurate and oversimplified environmental models, policies, and public understanding, with fire typically cast as generally detrimental to ecosystems, economies, and human health. While the academic community increasingly recognises the importance of fire to human culture and livelihoods, official policies in many countries still seek to eradicate human fire use.

The Global Fire Use Survey project is an international collaboration of academics and fire practitioners to create the first map of human fire use practices across the planet in the twenty-first century. Our map will have the potential to change narratives about fire and inform fire management debates and fire modelling efforts. It will challenge anti-fire narratives that do not discriminate between different fire users and practices, highlighting the widespread importance of human fire within livelihoods and ecosystems worldwide.

Participation in the survey

We welcome anyone to participate in the Global Fire Use Survey who has knowledge of human fire use specific to any region of the world. This knowledge might be gained through practice as a fire user or manager, or through research. We ask that participants have been 'in touch' with conditions in their region of expertise for at least some time in the period from 1990 to 2022.

Participants will remain anonymous unless they choose to provide their name and email address at the end of the survey. Participants can also indicate at the end of the survey if they would like to be acknowledged in any outputs from the research. Data will be stored in line with Royal Holloway's Data Management Policy. You have the right to withdraw your information up to the point that we begin analysis of the data (email c.smith@rhul.ac.uk if you want to withdraw).

Survey regions

Participants answer the survey questions for a specific region that they know well. The map of regions for the survey combines country boundaries, biomes/ecoregions, and precipitation data. The map of regions can be viewed here. The map includes regions where fire is **not** used by people. We are still looking for participants to confirm that this is the case for these regions.

Which of the following groups use fire in the landscape in this region?

You will answer the next questions in the survey separately for each group you have selected.

People who use fire to support small-scale livelihoods and/or for cultural reasons, such as smallholder farmers and Indigenous people
Households with 'small-scale livelihoods' rely mostly on family labour or labour exchange with other households, and might practice farming, pastoralism, hunting, fishing, and/or gathering, among other activities.
Smallholders are households for which agriculture is the principal source of livelihood and which rely mostly on family labour, or labour exchange with other households. Such households usually produce at least a proportion of their crops and/or livestock for household subsistence but may also produce a substantial amount for the market. Smallholder farm sizes can vary as the amount of land required to make agriculture a viable livelihood varies significantly in different parts of the world.

People working for commercial enterprises and/or large landholders
Commercial enterprises are oriented towards the market and employ workers. They include forestry enterprises, livestock farms, industrial agriculture, and private game reserves.

Protected area managers and/or people working for state agencies
Protected area managers may be employed by governments, or non-governmental organisations (NGOs).
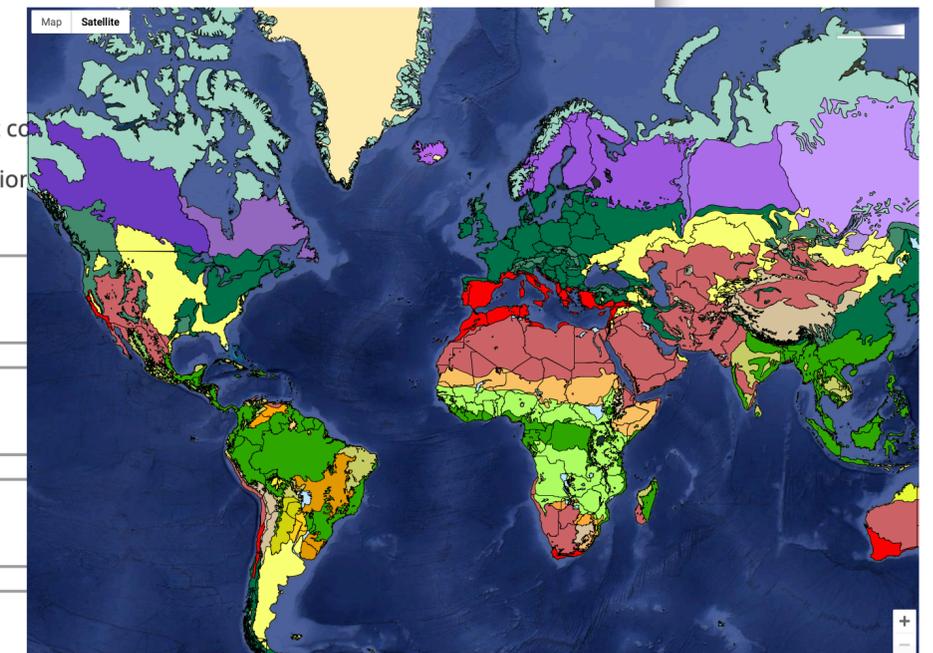
On a scale of 1 to 5 (with 1 being least co...
were you in your answer to this question...

1

2

3

4

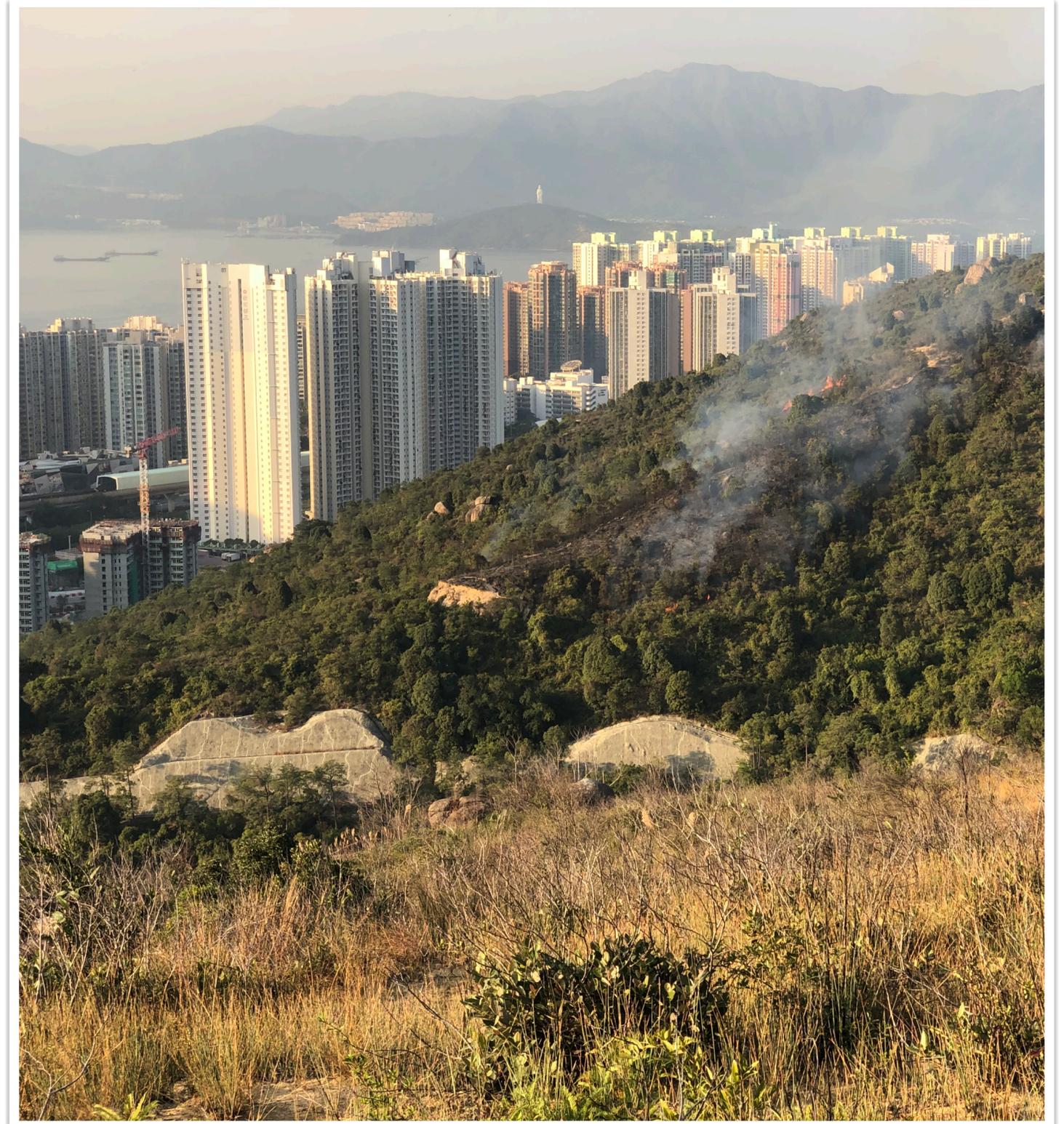Cathy Smith, Jay Mistry, and the human use of fire survey group

- Lack of data on fuels, particularly in developing countries

- Future land use projections, especially as they relate to anthropogenic fire ignitions, suppression, and fuels management

- Ability to observe and simulate very small fires, particularly as part of smallholder land management

New Territories, Hong Kong, December 2020

Measures to bring us closer to reality

- More detailed information on the current state of fuels

  - LANDFIRE-type fuel models for all global ecosystems

  - Regular measurements of fuel characteristics: height, density, time since last fire ← remote sensing

- More granular information on human use of fire: ignitions, suppression, policies, practices

  - Global fire use survey, interviews, policy analyses

- Even with perfect data and models on fire at the present, future fire will depend on understanding how the relationship between humans and fire evolves over the next century.

- This is beyond the domain of physical scientists.

- We need to create a wider range of scenarios tied to SSPs.