

# Machine Learning-based Observation-constrained Projections Reveal Elevated Global Socioeconomic Risks from Wildfire

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# Fire in the Earth System



# Historical and Projected Wildfire Activities in CMIP6 ESMs



### Ways to Reduce ESM Projection Biases



Core concept of **Emergent constraint**: despite major differences across ESMs, relationships between elements of **current climate (X)** and **future climate (Y)** are implicit **within ESM** solutions of the partial differential equations governing physical and biogeochemical systems, i.e., **Y = f(X) + ε, where f is** *identified from a suite of ESMs.* Hall et al. (2019)

# **Limited Applicability of Traditional Emergent Constraint**





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#### Wildfire Machine Learnings

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Jain et al. (2020)

# **Predictability of African Fire Carbon Emission**



# Schematic of the ML-EC Framework



Training dataset: the spatial sample (at  $0.25^{\circ}$  lat/lon) of decadal mean predictors and target variable (N = 11,325 for each ESM).



# Validation of the Analytical Framework



**CAK RIDGE** Use fire-relevant variables during 1997-2006 to predict fire carbon emissions during 2007-2016.



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Fire carbon emission during 2090s (kg m<sup>-2</sup> yr<sup>-1</sup>)



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Trend in fire carbon emission (kg m<sup>-2</sup> yr<sup>-1</sup> dec<sup>-1</sup>)





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yr<sup>-1</sup> **m**-2 (kg emission carbon fire **Trend in** 



# **Socioeconomical Exposure to Wildfire Changes**





Decadal mean population (GDP, agricultural area) exposure = population (GDP, agricultural area) x fire carbon emission. Sum over all pixels in a country and then calculate trend.

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## **Importance of Historical Predictors for Future Fire**

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# **Importance of Factors' Trend to Future Fire**



- In ML constrained, apply the current observational constraining framework to all fire-relevant variables;
- Obtain trends in all these fire-relevant variables;

 Assess the relative importance of these variables in regulating the spatial distribution of future fire carbon emissions for different regions;

#### **Scenario-dependent Projections**



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# **Historical Observations**



Burned area fraction in 2016 from satellite products with different spatial resolution (Ramo et al., 2021).



### **Models and Feedbacks**

CMIP6 Model	Resolutio n (km)	Ensemble members	Land model	Fire model description	Global climate system Bowman et al., 2020
					Increased Drought stress
CESM2	100	3		Natural and anthropogenic ignition sources and suppression of agricultural,	Fossil-fuel emissions     Increased     Atmospheric CO, and
CESM2-WACCM	100	5	CLM5		Altered • Urban heat islands • Altered albedo other GHG emissions
CMCC-ESM2	100	1	CLM4.5	deforestation, and peat fires <sup>2,3</sup>	Biogeography Reduced C storage More extreme Fire weather Surface albedo
CNRM-ESM2.1	250	5	SURFEX∨8. 0 (ISBA)	Interactive natural fires <sup>5</sup>	Altered Biodiversity C cycling Increased
E3SM-1.1	100	1	ELM v1.1	Same as CLM5	Post-colonial Post-fire hydrology
EC-Earth3-CC	100	1			Altered Altered Altered
EC-Earth3-Veg- LR	250	3	LPJ-GUESS v4	Interactive natural fires <sup>7</sup>	Altered     Surface albedo       Growth rates     Fire regimes       Reduced       Cryosphere stability
EC-Earth3-Veg	100	5			Land-use change     WUI expansion
GFDL-ESM4	100	1	LM4.1	Distinct parameterizations for natural and agricultural wildfires, especially representing multiday and	<ul> <li>Invasive species</li> <li>Removal of grazers</li> <li>Indigenous/cultural fire removal</li> <li>Altered Vegetation trajectories</li> </ul>
				crown wildfires <sup>9</sup>	Altered Ecological succession
MPI-ESM1-2-LR	250	10	JSBACH3. 20	Natural fires ignited by human activity and lightning,	Reduced Biodiversity     Diminished Ecological function
				with up to 12-hour duration <sup>10</sup>	Altered Fuel structures
MRI-ESM2	100	1	HAL 1.0	N/A	Altered Fire regimes     Vegetation     Wildfire     Wildfire
NorESM2-LM	250	1	CLAAF	Samo as CLAAE	increased intensity
NorESM2-MM	100	1	CLM3		<ul> <li>Insufficient representation of those processes in ESMs</li> </ul>
<b>OAK RIDGE</b>	ESMs A	Analyze	d in This	Research	<ul> <li>Offline projection in current ML constraining framework</li> </ul>

**CAK RIDGE ESMs Analyzed in This Research** 

## **Take-home Messages**

Credibility of future wildfire simulations by latest ESMs remains low because of modeling uncertainties and insufficient application of observational constraints for ESMs;

- New ML-based EC framework is particularly useful for prediction and projection of variables with complex driving factors, such as wildfire regimes and extreme climates;
- Constrained results showed further enhancement of wildfire activities in the historically fire-prone regions;
- Concurrently enhanced wildfire activity and socioeconomic development call for mitigation and/or adaptation strategies to minimize potential socioeconomic loss caused by wildfires;



# Thanks for Your Attention! Questions and Comments?

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