Coupling interactive fire with atmospheric composition and climate in the UK Earth System Model (UKESM)

João Teixeira[1,2], Gerd Folberth[1], Fiona O'Connor[1], Nadine Unger[2], Apostolos Voulgarakis[3,4]

[1]Met Office, Fitzroy Road, EX1 3PB, Exeter, UK
[2]College of Engineering, Mathematics and Physical Sciences, University of Exeter, Exeter, UK
[3]Department of Physics, Imperial College London, London, UK
[4]School of Environmental Engineering, Technical University of Crete, Chania, Greece

Introduction

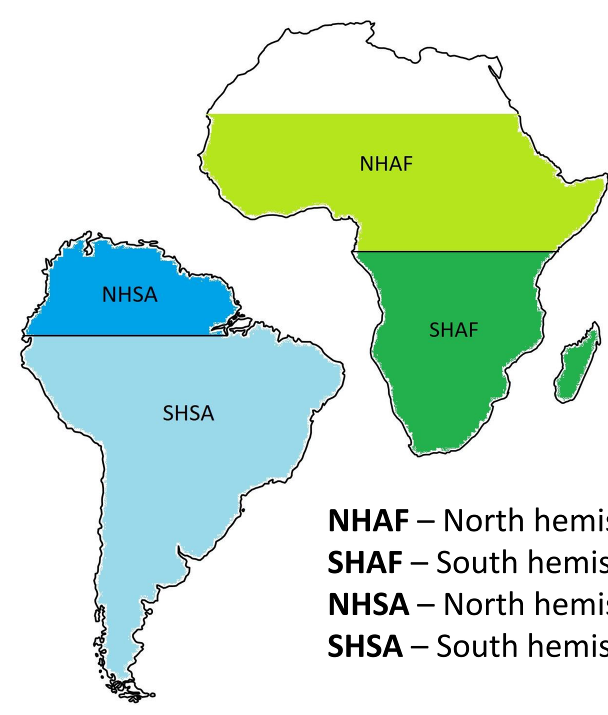
The sum radiative effect of fires remains uncertain making it relevant in the context of climate change research. Considering this, together with the varying projections of future climate, it is important to highlight the low agreement about the direction of regional changes in future fire regimes as stressed in the IPCC Fifth Assessment Report. Ward et al. (2012) showed that even though models may have an overall similar net change in radiative forcing over time, this net forcing can be driven by different sources - background anthropogenic and natural emissions or biomass burning emissions - which balance each other to obtain the same net result. Voulgarakis and Field (2015) showed that fires play a large and even dominant role in driving the interannual variability of key trace gases and aerosols that influence air quality and climate.

Observation Data

Global Fire Assimilation System (GFAS)
- carbon monoxide (CO)
- black carbon (BC)
- organic carbon (OC)

Tropospheric Emission Spectrometer (TES-AURA)
- Carbon monoxide (CO)

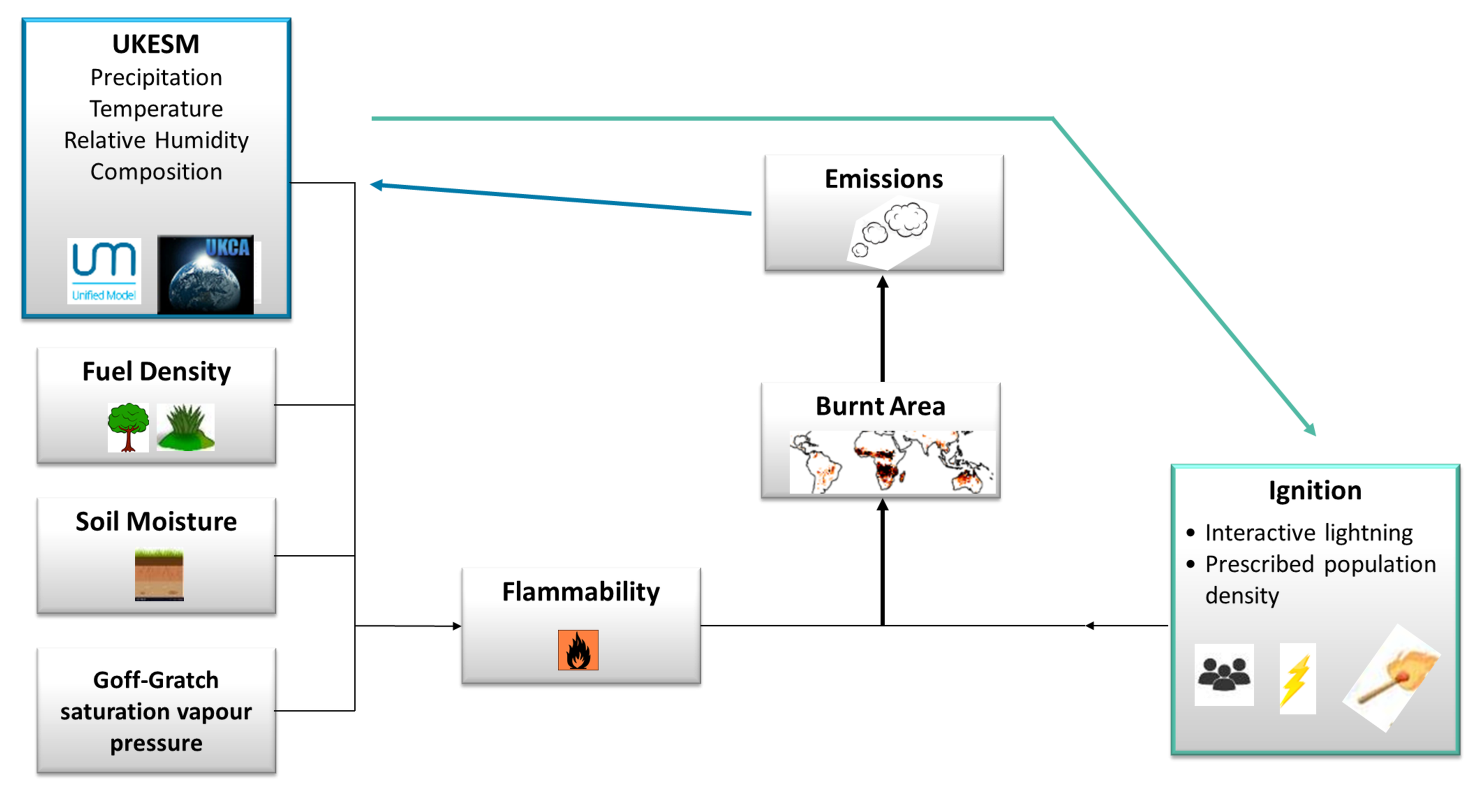
Combined MODIS Dark Target and Deep Blue algorithms (MODIS)
- Aerosol optical depth (AOD)



NHAF – North hemisphere Africa
SHAF – South hemisphere Africa
NHSA – North hemisphere South America
SHSA – South hemisphere South America

Objective

Development and evaluation of a fully coupled fire-climate-composition ES model, based on the:
- INteractive Fires and Emissions algoRithm for Natural envirOnments (INFERNO Mangeon et al. (2016))
- UKESM1 – AMIP (Sellar et al. 2020).



Results

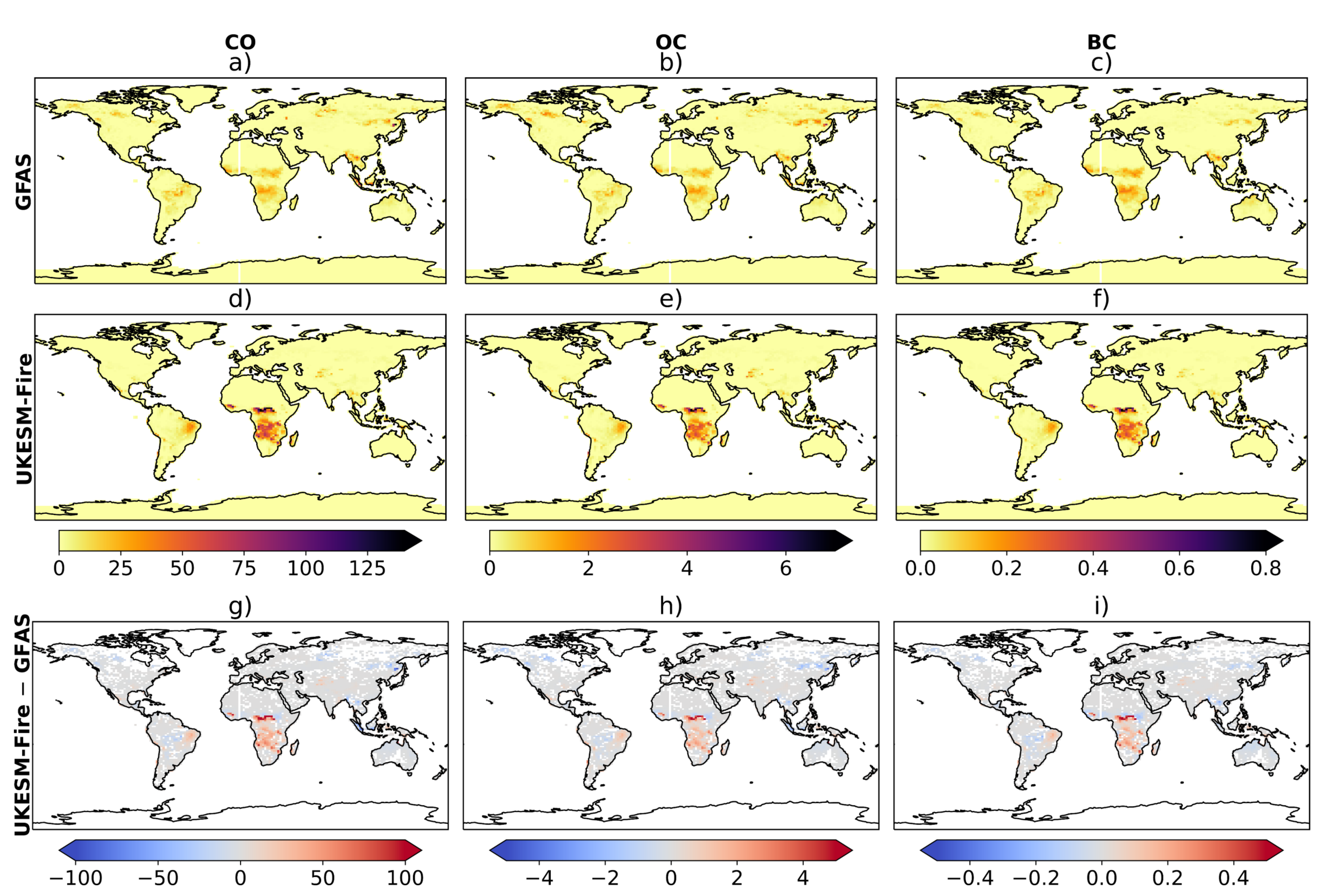


Figure 1: Biomass burning emissions (kg m^{-2}) mean annual average (1997 - 2010). Differences are only shown for statistically significant points with a 95% confidence level.

Comparing biomass burning emissions from the coupled interactive fire with UKESM1

- Global pattern for annual average biomass burning emissions are well reproduced
- Large overestimation of the biomass burning emissions in the southern edge of NHAF, SHAF and eastern side of SHSA (difference > 300 %)
- For the SHAF region the emissions extend further south into the midlatitudes when compared to GFAS
- For boreal regions there is an underestimation of the biomass burning emissions in the order of 100 %
- global pattern correlation for biomass burning emitted species of 36.7 % for CO, 38.4 % for OC and 53.2 % for BC when compared with GFAS

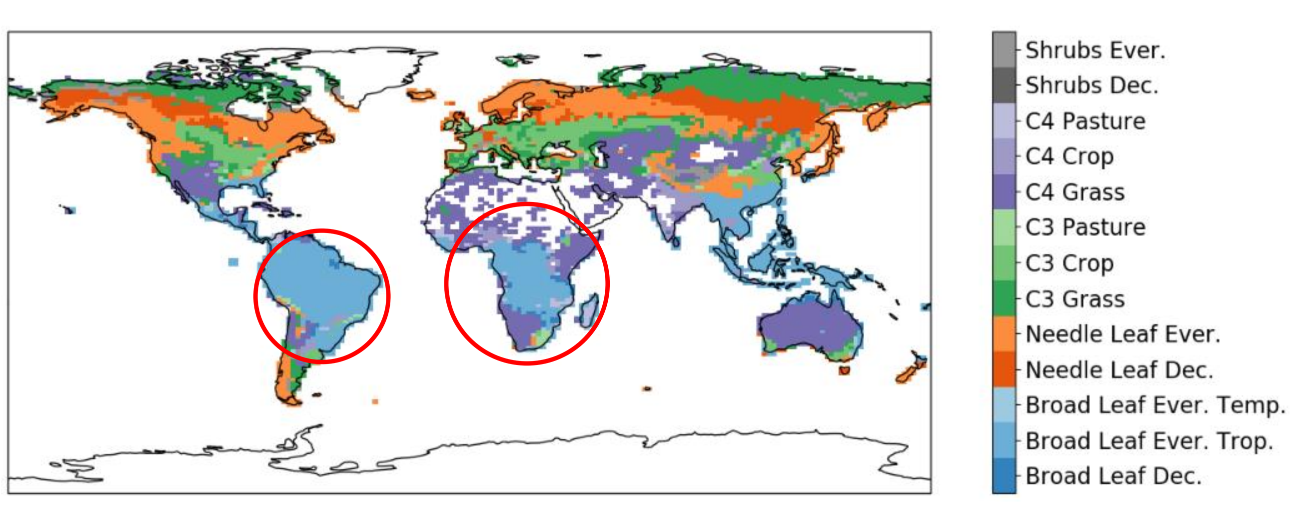


Figure 2: Dominant vegetation Plant Functional Type (PFT) per grid-box for as prescribed in UKESM1 - AMIP.

Bias in underlying vegetation: Overestimation of tree fraction in savanna biomes impacts the fire model causing:
- underestimation of burnt area
- Overestimation of biomass burning emissions

Comparing UKESM-Fire to TES-AURA carbon monoxide and MODIS AOD

- Overestimation of CO over NHAF and SHAF → bias in the emissions
- Interactive configuration has similar performance to UKESM1 – AMIP
- Interactive configuration improves interannual CO variability and seasonality over the studied regions
- overestimation of AOD over the biomass burning regions in NHAF and SHAF
- improvement of the variability and seasonality of AOD in South America,
- Interactive configuration does not capture the spikes in AOD, or CO observed over SHSA during the period 2004 to 2007 and 2010

associated with the Amazonia fire events that generally occur in drought years often related to El Niño events.

Capturing these specific events depends on the ability of the model to represent circulation regimes that lead to the drought during the simulated period.

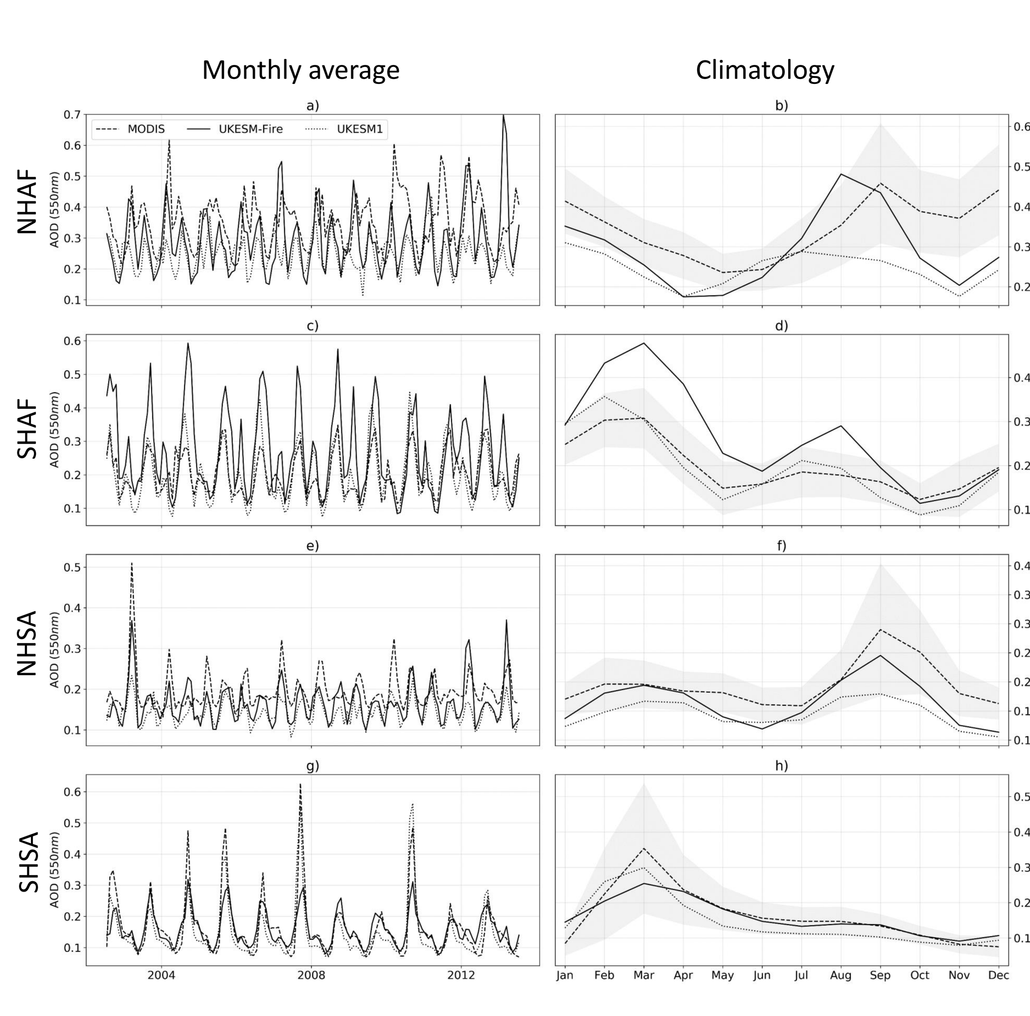


Figure 3: Aerosol optical depth at 550 nm for the period 2003 – 2012 – UKESM-Fire (solid line), UKESM1 (dotted line) and MODIS (dashed line).

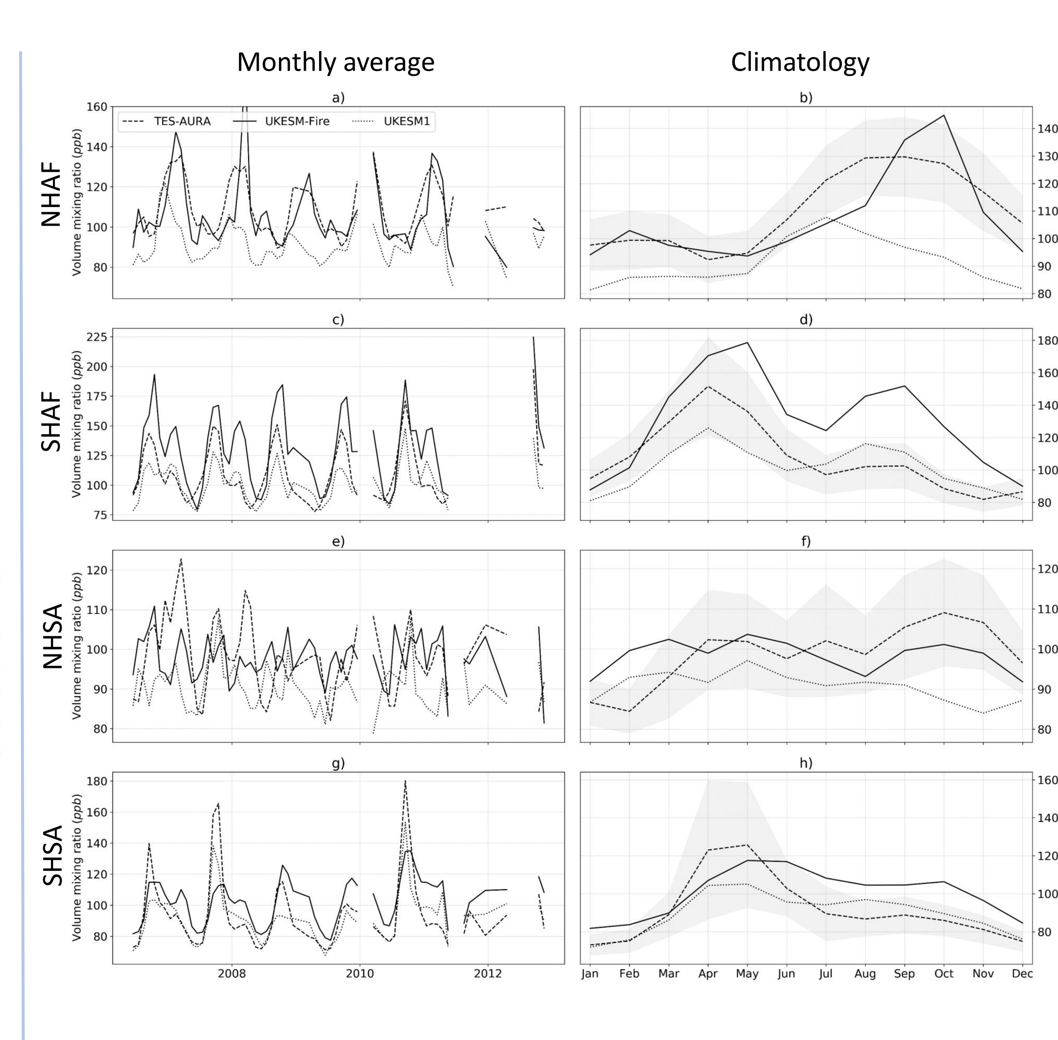


Figure 4: Column volume mixing ration carbon monoxide (ppm) averaged between 700 and 300 hPa for the period 2007-2012 – UKESM-Fire (solid line), UKESM1 (dotted line) and TES-AURA (dashed line).

Conclusions

Despite the present limitations of the implementation of coupled fire-composition-climate processes in this framework, it is possible to see the adding an interactive fire model UKESM has a similar performance in reproducing the distribution of aerosols and CO atmospheric column. This shows that framework provides a useful coupling framework that allows the representation of fire-composition-climate complex interactions and feedbacks in the Earth's climate. With further work to improve the existent model errors and bias, UKESM with interactive fire can provide a useful framework to quantify the impacts of fire variability on atmospheric composition-climate interactions in past, present and future climates.

References

Mangeon et al. (2016) – https://doi.org/10.5194/gmd-9-2685-2016
Sellar et al. (2020) – https://doi.org/10.1029/2019MS001946
Voulgarakis and Field (2015) – https://doi.org/10.1007/s40726-015-0007-z
Ward et al. (2012) – https://doi.org/10.5194/acp-12-10857-2012

Met Office Hadley Centre, FitzRoy Road, Exeter, Devon, EX1 3PB United Kingdom
Tel: +44 1392 885680 Fax: +44 1392 885681
Email: joao.teixeira@metoffice.gov.uk