The Fire Radiative Energy Emission (FREM) Approach

New Applications from Australia to High Latitudes

NCEO Staff Conference 2025

Dr. Will Maslanka
Prof. Martin Wooster
Dr. Zixia Liu
Dr. Jiangping He

Kings College London

KING'S College LONDON

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

UKRI Natural Environment Research Council

Background and Motivation

Landscape fires are amongst the largest contributor of gaseous and particulate emissions into the atmosphere.

- Occur on every vegetated continent except Antarctica
- 347 Megatonnes of CO annually emitted globally
- 25 Megatonnes emitted from the High Latitudes (≥ 60°N)

Global climate change is altering the conditions that impact wildfire regimes

- Warmer temperatures, regionally decreased precipitation
- Accelerated warming in the high latitudes
- Organic soils / peat in permafrost now available for burning

Annual Landscape fire CO emissions

Global	Australia	≥ 60°N
2003: 430.5 Tg	2003: 16.2 Tg	2003: 24.4 Tg
2004: 393.9 Tg	2004: 24.5 Tg	2004: 28.5 Tg
2005: 388.6 Tg	2005: 12.7 Tg	2005: 22.3 Tg
2006: 388.8 Tg	2006: 24.3 Tg	2006: 10.0 Tg
2007: 366.0 Tg	2007: 22.0 Tg	2007: 8.7 Tg
2008: 340.5 Tg	2008: 12.2 Tg	2008: 5.0 Tg
2009: 332.1 Tg	2009: 17.9 Tg	2009: 22.5 Tg
2010: 326.0 Tg	2010: 7.9 Tg	2010: 18.3 Tg
2011: 342.9 Tg	2011: 36.3 Tg	2011: 12.7 Tg
2012: 400.2 Tg	2012: 39.2 Tg	2012: 41.9 Tg
2013: 294.6 Tg	2013: 14.0 Tg	2013: 28.2 Tg
2014: 365.8 Tg	2014: 19.7 Tg	2014: 36.2 Tg
2015: 450.2 Tg	2015: 18.0 Tg	2015: 12.6 Tg
2016: 330.6 Tg	2016: 11.5 Tg	2016: 20.0 Tg
2017: 281.8 Tg	2017: 19.3 Tg	2017: 23.6 Tg
2018: 289.0 Tg	2018: 21.5 Tg	2018: 22.1 Tg
2019: 364.7 Tg	2019: 26.2 Tg	2019: 29.3 Tg
2020: 265.2 Tg	2020: 12.9 Tg	2020: 35.5 Tg
2021: 313.4 Tg	2021: 9.6 Tg	2021: 61.3 Tg
2022: 244.1 Tg	2022: 9.7 Tg	2022: 16.7 Tg
2023: 382.6 Tg	2023: 29.2 Tg	2023: 41.4 Tg
2024: 335.6 Tg	2024: 13.7 Tg	2024: 36.4 Tg
Mean: 346.7 Tg	Mean: 19.0 Tg	Mean: 25.3 Tg

Estimating Emissions

EO can be used to observe fires through **Burned Area**, **Fire Radiative Power (FRP)**, and/or **Smoke in the Atmosphere**.

- Observing smoke doesn't tell you the emission, but the *result* of the emission.
- Observing Burned Area needs a *lot of assumptions* to relate to fire emission (GFED).
- Previously, FRP has been used with a conversion factor → fuel consumption rate (*lab based*)

Our solution: Directly relating EO FRP observations to EO Smoke Plume observations

- Remove the need for lab-based conversion, independent of other inventories

Bottom-Up (In-direct)

(measured) Burnt Area Active Fires + (modelled) Pre-fire fuel load + (modelled) Combustion Completeness

GFED

GFAS

(estimated) Emissions

Uncertainties? Assumptions?

Top-Down (Direct)

FEER

FREM

(measured) Satellite FRP → (estimated) Emissions

Quantified Uncertainties

Based on Observations so Very Limited Assumptions

FREM Approach

Fire Radiative Energy Emissions (FREM)

Based on Fire Radiative Power (FRP) timeseries

- v1: related MSG FRE to TPM (Africa)
- v2: method improved, also related MSG FRE to CO (Africa)

Applied in Real Time, independent of others

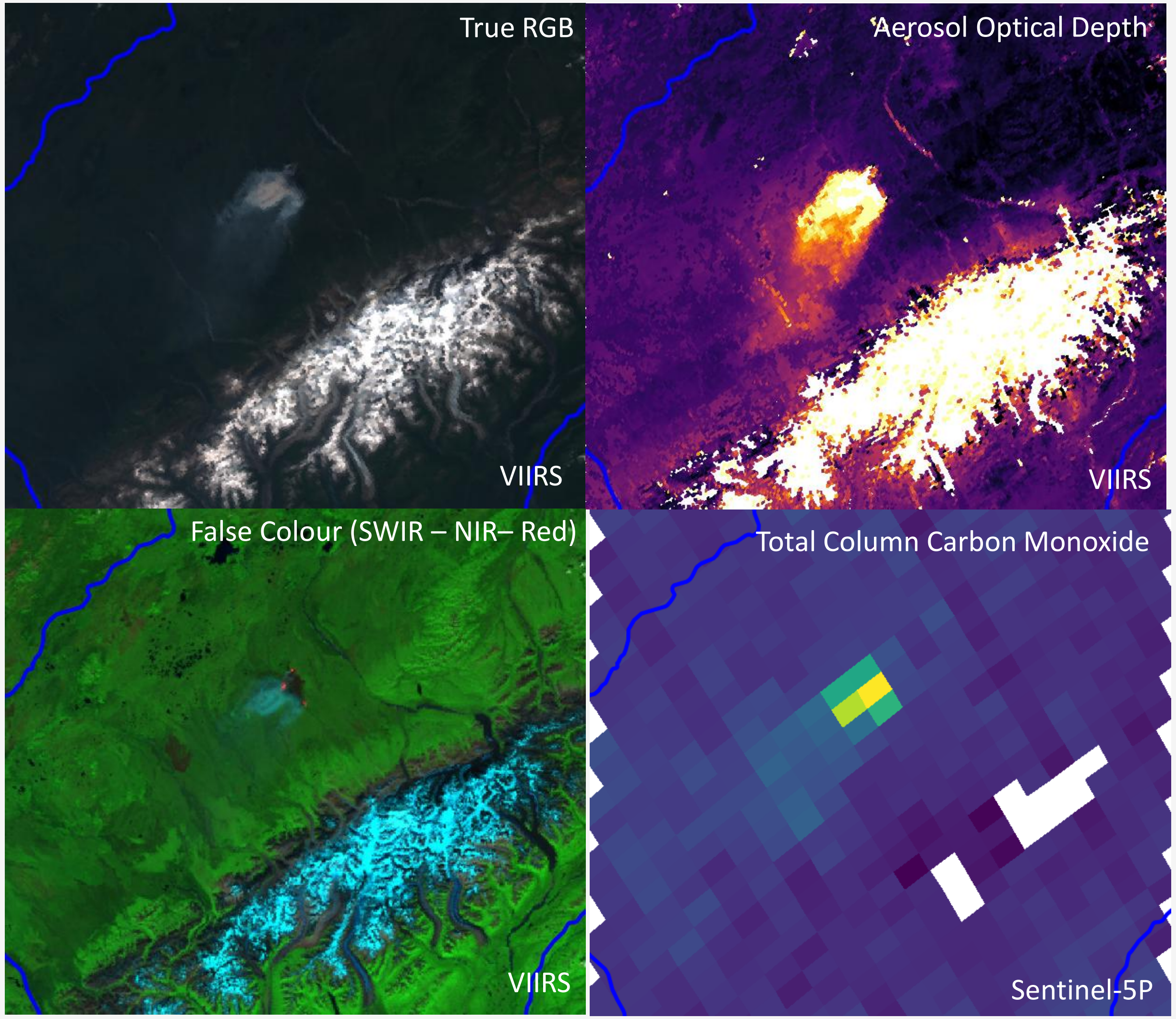
- GFED has 1 year lag (reliant on other models)
- GFAS is NRT, but is not independent from GFED

HL-FREM (Latitudes ≥ 60°N)

- Swap MSG FRE for Polar Orbiter FRP
- Orbital Convergence provides many samples per day

AU-FREM (Australia)

- Swap MSG FRE for Himawari FRE



FREM Approach

Data Used

CCI 2018 Land Cover
Koppen Climate Classes
Aggregated FREM Biomes

VIIRS (S-NPP)
Plume Identification
Fire Identification

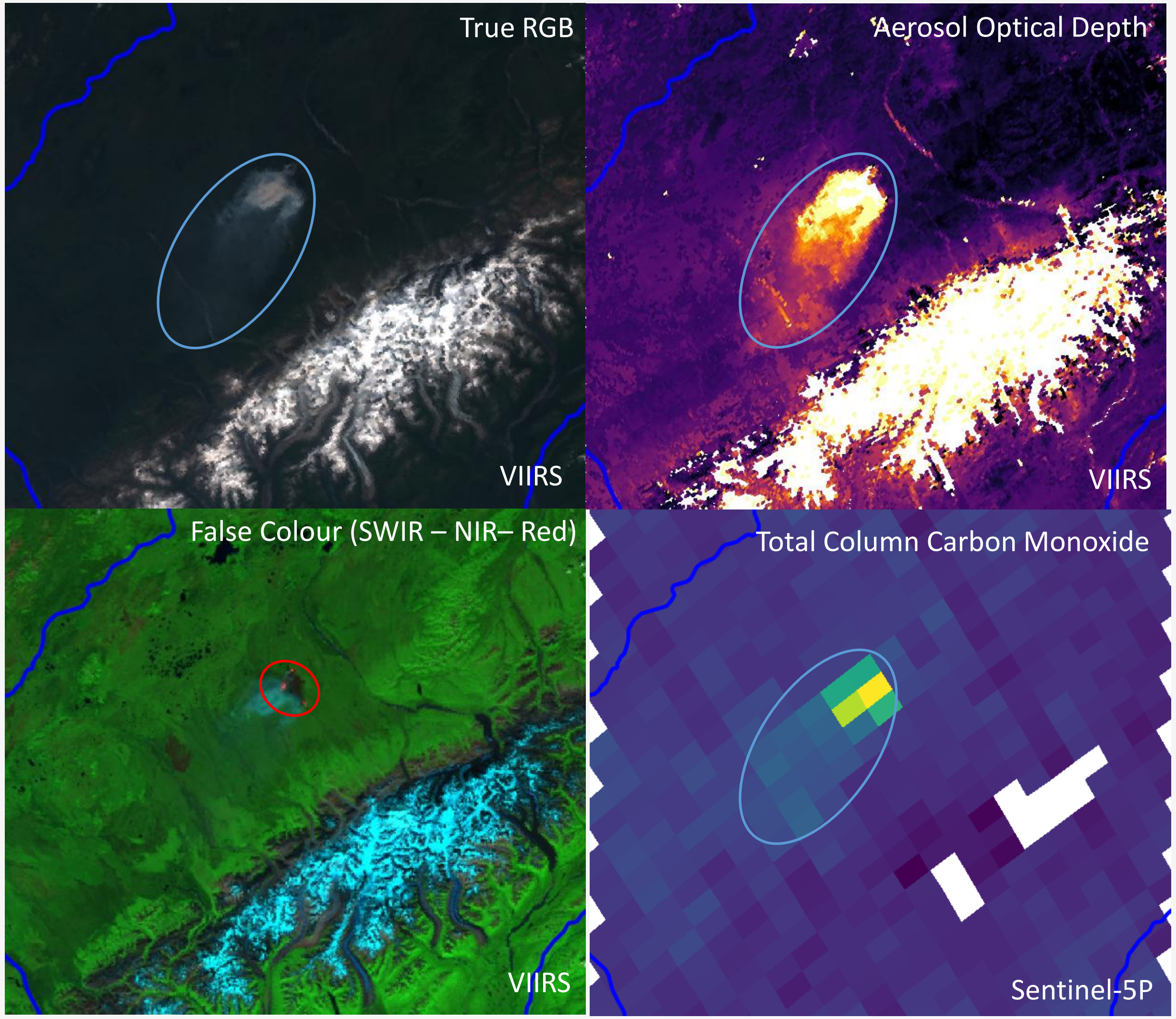
TROPOMI (Sentinel-5P)
Total Column Carbon Monoxide Observations

GFAS v1.4
MODIS Hourly FRP
(HL-FREM)

Himawari-8 FRP-PIXEL
Himawari-8 10 min FRP
(AU-FREM)

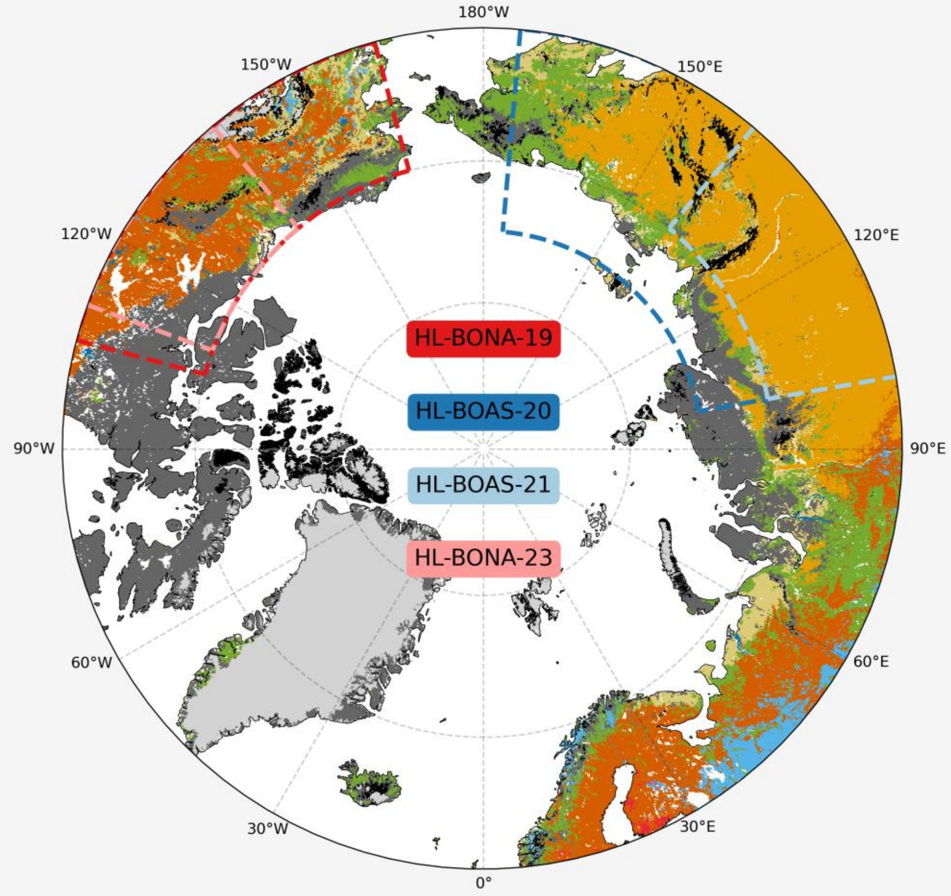
HL-FREM
833 Plumes Digitized
JJA 2019, 2020, 2021, 2023

AU-FREM
826 Plumes Digitized
2019

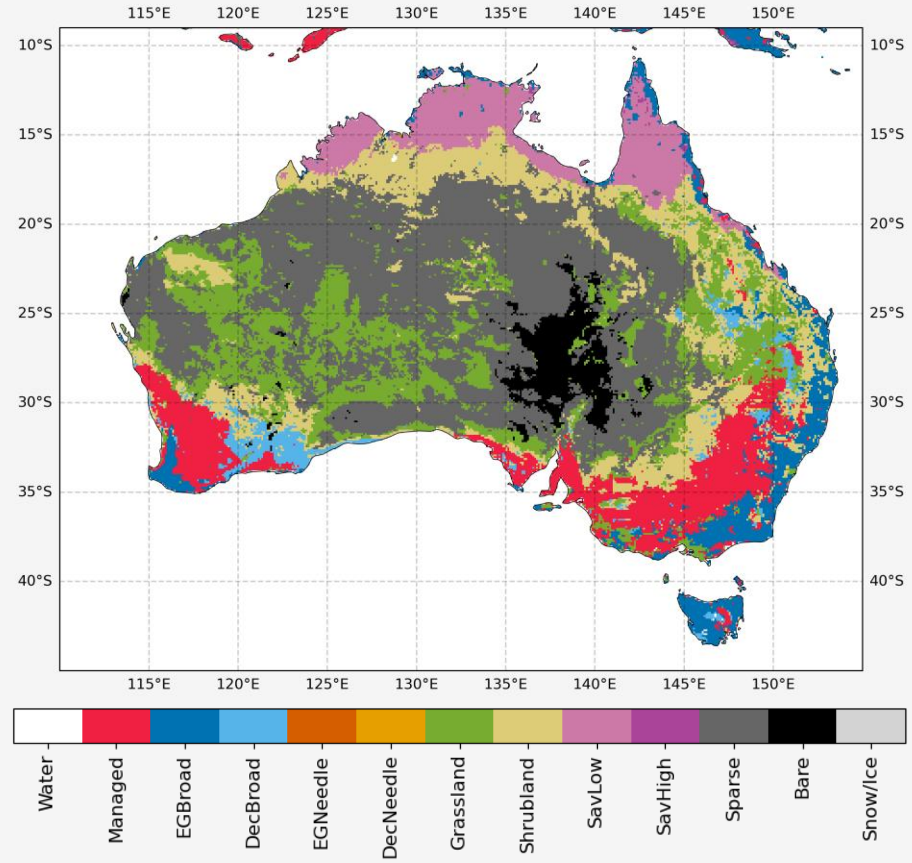


FREM Regions of Interest

HL-FREM



AU-FREM



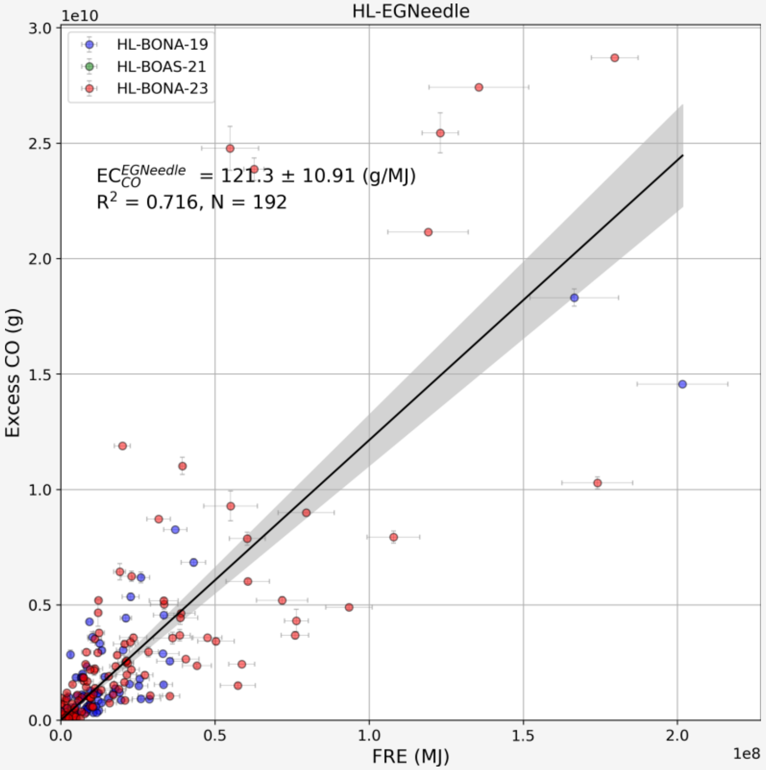
FREM Emission Coefficients

HL-FREM

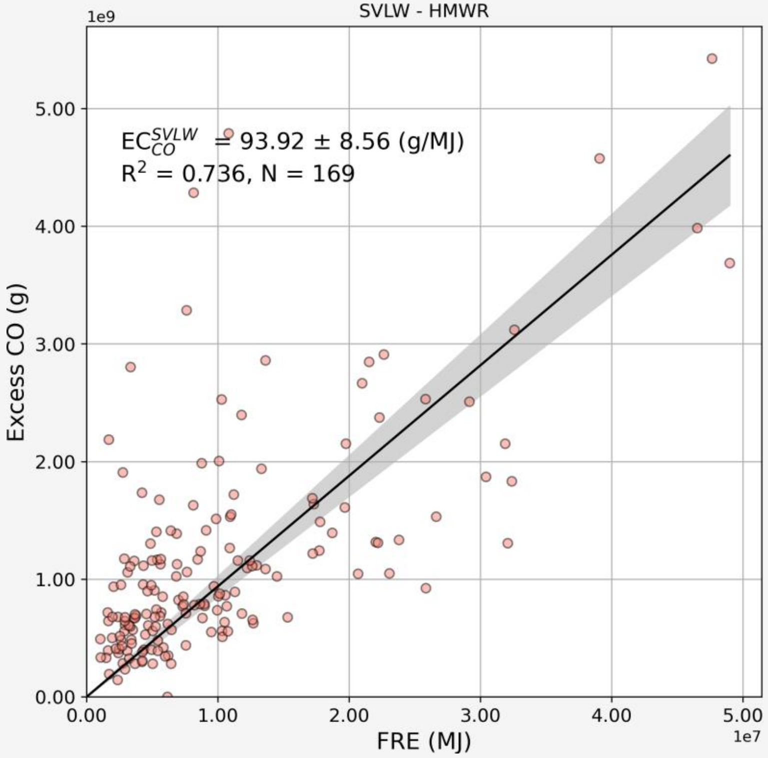
HL-FREM EC^{b}_{CO}

DecNeedle
EGNeedle
Grassland
Shrubland

≈ 93% of HL FRE



AU-FREM

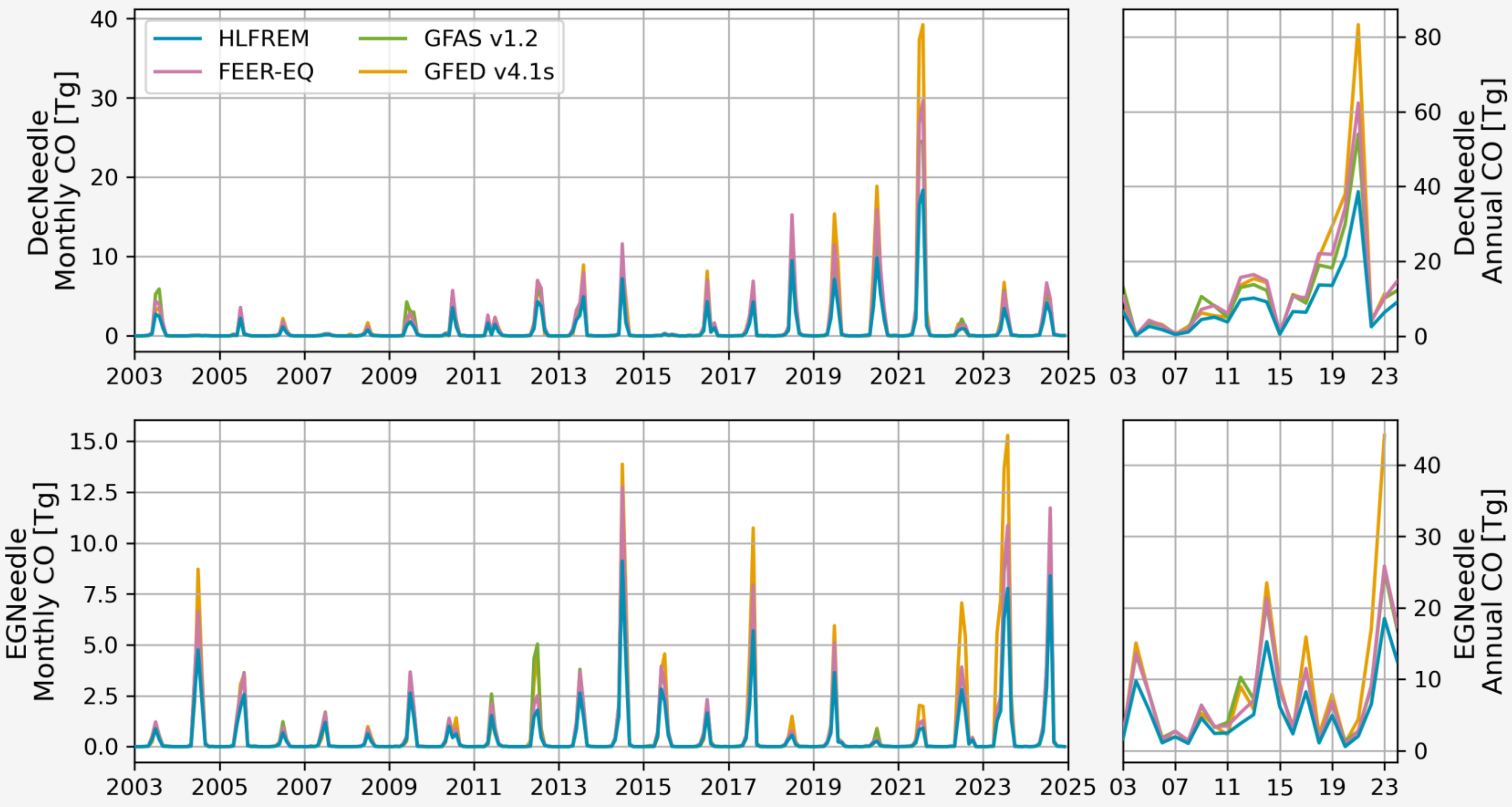


AU-FREM EC^{b}_{CO}

Low Savannah
DecBroadleaf
EGBroadleaf
Agriculture
Shrubland
Grassland
Sparse

≈ 98% of AU FRE

HL-FREM CO Inventory Comparison

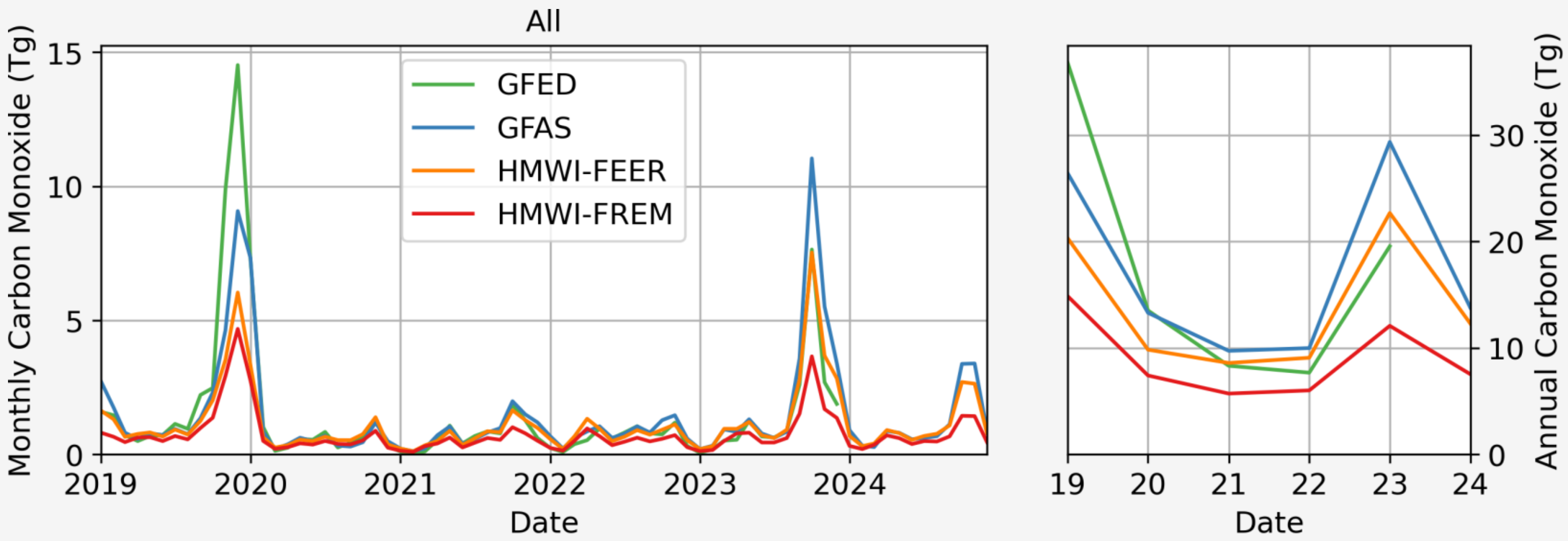


	DecNeedle	EGNeedle	Grassland	Shrubland
HLFREM	7.8 Tg	5.0 Tg	0.8 Tg	0.5 Tg
FEER	12.6 Tg	7.0 Tg	2.3 Tg	0.7 Tg
GFAS (v1.2)	11.5 Tg	7.2 Tg	4.0 Tg	0.8 Tg
GFED (v4.1s)	13.6 Tg	8.7 Tg	2.1 Tg	0.7 Tg

Mean annual (2003 – 2023) CO emissions

Direct Estimation of Wildfire Emissions at High Latitudes from Combined Polar Orbiter FRP and Sentinel-5P CO Data (under review, ACP)

AU-FREM CO Inventory Comparison



	Mean Monthly CO	Total CO July 19 – Jan 20	Total CO July 23 – Dec 23
HLFREM	0.7 Tg	13.9 Tg	9.3 Tg
FEER	1.2 Tg	17.8 Tg	18.4 Tg
GFAS (v1.2)	1.4 Tg	26.4 Tg	25.0 Tg
GFED (v4.1s)	1.4 Tg	38.4 Tg	16.3 Tg

Work is ongoing…

- Quality Assessment on Plume Selection, FRE calculation
- Additional Emission assessment and comparison using Emission Factors
  - CO_2, CH_4, Total Carbon
- Estimates of Fuel consumption per unit area from EO sources only

$$EC_x^{biome} = \frac{EF_x^{biome}}{EF_{CO}^{biome}} EC_{CO}^{biome}$$

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

UKRI Natural Environment Research Council

Summary

Fire Radiative Energy Emissions (FREM)

- Directly linking Satellite FRP to Satellite Emissions (TPM/CO)
- First Direct Estimation of Fire CO emissions in HL Forest, Grasslands, and Shrublands

Comparisons with Existing Fire Emission Inventories

- Shown to be temporally consistent with pre-existing inventories
- Can estimate other emissions (CH4, CO2, C, etc) through Emission Factors

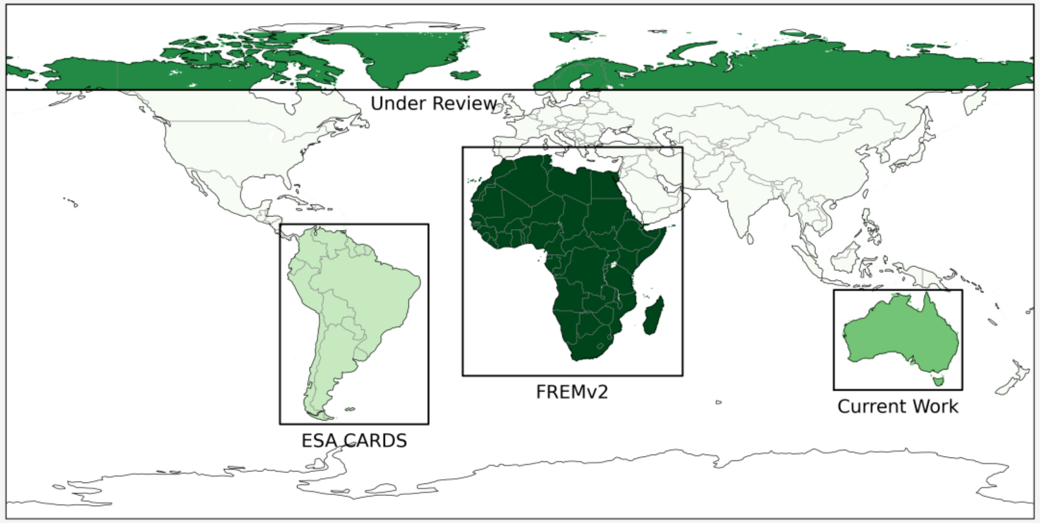
Advantages of FREM

- Doesn’t rely on modelled parameters
- Applied in Real Time

Looking to the future…

- Current focus is Australia
- S. America: ESA CARDS
    - CarbonARA in Brazil

Questions?



KING'S College LONDON