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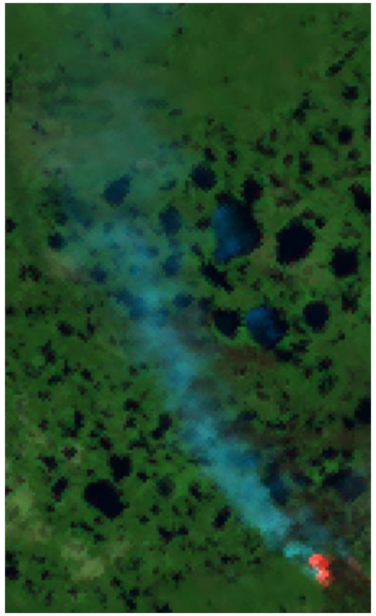
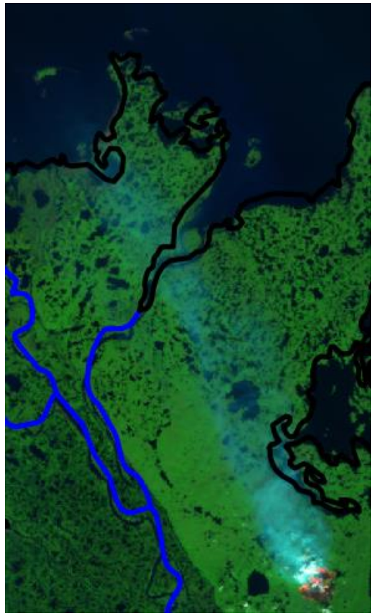
Direct Estimation of Carbon Emissions from High Latitude Fires: The Adapted FREM Approach

Dr. Will Maslanka, Prof. Martin Wooster

Abstract





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Context

At high latitudes, global climate change is exacerbating conditions that impact and alter wildfires regimes

- Larger and more frequent fires, lengthening of fire season
- Warmer temperatures, regionally decreased precipitation[1]
- July 2023 “2nd warmest on record” – increase in wildfire news stories

Warming is accelerated in higher latitude regions, and increases the risk of high-latitude feedback mechanisms

- Release of carbon sequestered in high-latitude peatlands / permafrost
- Black carbon deposits on ice increasing rate of melting

Effective monitoring of high-latitude fires and emissions imperative for climate monitoring and reporting.

[1] IPCC 2019: Land-Climate Interactions in Special Report: Climate Change and Land

BBC NEWS

Nova Scotia battles its largest wildfire on record

1 June

Canada wildfire smoke leaves millions under air quality advisory

18 July

Canada wildfires: At least 30,000 households in British Columbia told to evacuate

3 days ago

Canada wildfire season is now the worst on record

29 June 2023

Canada wildfires: Residents scramble to flee fires in Kelowna and Yellowknife

18 August 2023

The FREM Approach: Current and Adaptation

One approach to estimate emissions from observations of Fires is through the top-down Fire Radiative Energy Emission (FREM) approach.

- Directly linking observations of FRP/FRE to TPM and (more recently) directly to CO to estimate emissions.
- Grouping these observations via biomes, can get a biome specific emission coefficient for species X, EC_X^{biome}
- Previous work has focused on Africa[2, 3] and SE Asia[4], taking advantage of high temporal sampling with Geostationary Platforms.

This approach not valid for the high-latitudes, due to poor spatial resolution (if visible).

- For high-latitude fire prone areas, geostationary pixel area ≈ 20km.
- High-latitude adaptation (aFREM): substituting Polar Orbiting platforms for Geostationary.

[2] Mota and Wooster 2018: 10.1016/j.rse.2017.12.016
[3] Nguyen et al 2023: 10.5194/acp-23-2089-2023
[4] Fisher et al., 2020: 10.3390/s20247075

Data and High Latitude Region(s) of Interest

VIIRS onboard Suomi-National Polar-orbiting Partnership (S-NPP)

- 375m / 750m spatial resolution
- Multispectral data, including derived fire radiative power (FRP) product
- Seen as the replacement for MODIS

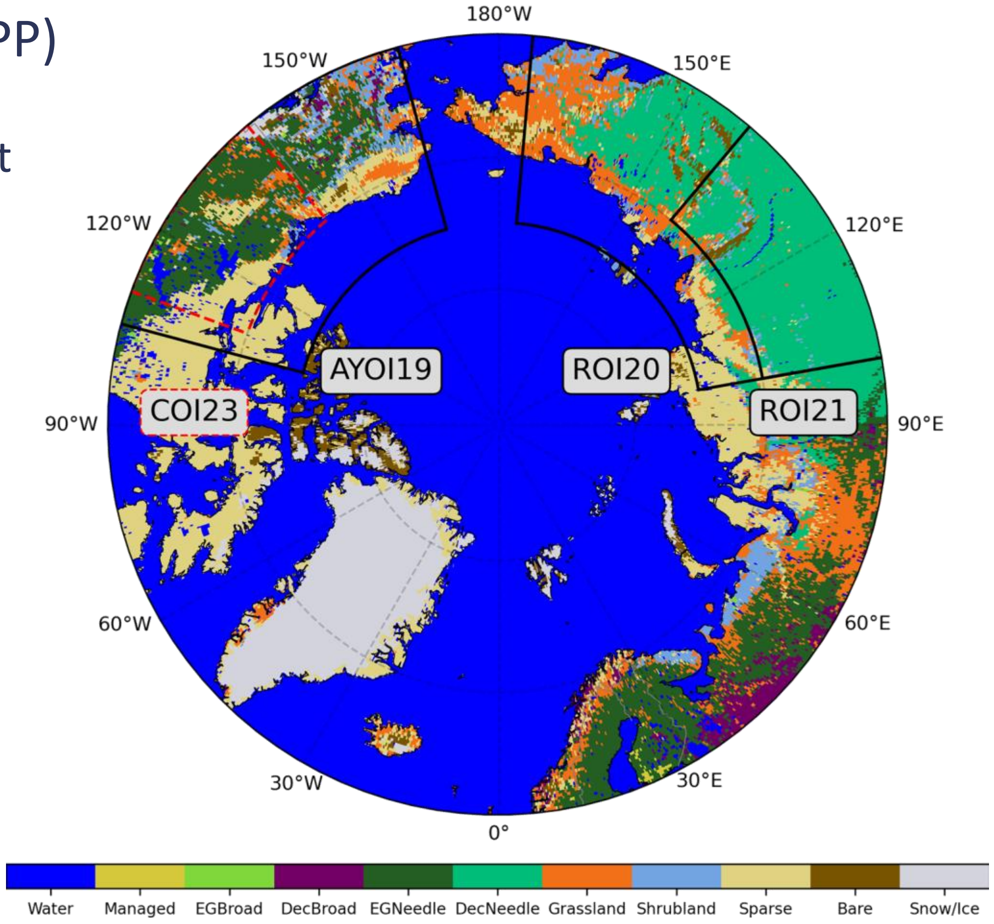
TROPOMI onboard Sentinel-5P

- 7.0 x 5.5km spatial resolution, trace gas products including CO
- Near-simultaneous observations with S-NPP

Hourly Gridded FRP from locally ran "development" GFAS

- Using S-NPP FRP as input, rather than MODIS
- S-NPP capable of detecting far lower FRP fires than MODIS can

ESA CCI Land Cover Map (2018, 300m resolution)



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aFREM Method – Excess “in plume” Mass of CO Estimation

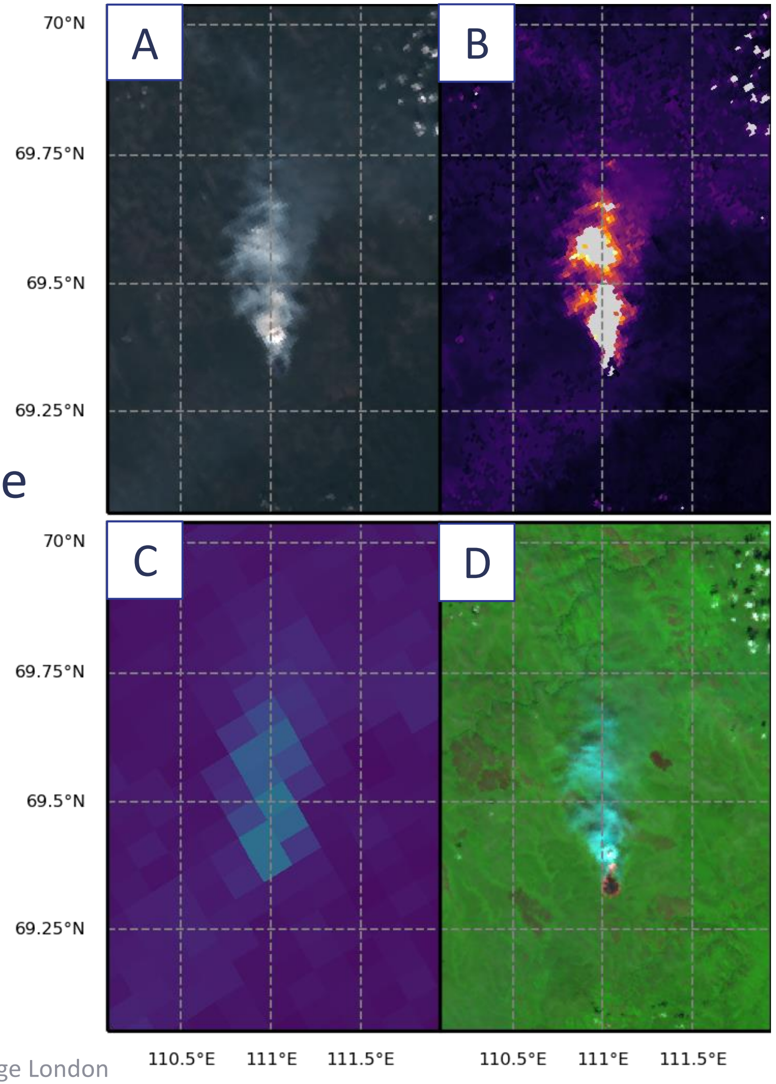
Locating “well observed” (cloud-free) fires and smoke plumes

- Finding Plumes in RGB imagery (A) and AOD_{550} (B)
- Digitize Plumes using RGB imagery (A) and AOD_{550} (B)
- Extracting Excess CO from Sentinel-5P (C)
  - Excess CO = $\Sigma [CO_{Obs} - CO_{Bgd}]$

Locating these fire-plume “matchups” only needs to be done in the “setup” stage.

- Identified matchups provide the emission coefficients linking the total FRE emitted to total excess CO release.
- These coefficients can then be applied to all FRP data; not just those of the match up fires.

Potential for AI automation of plume mapping



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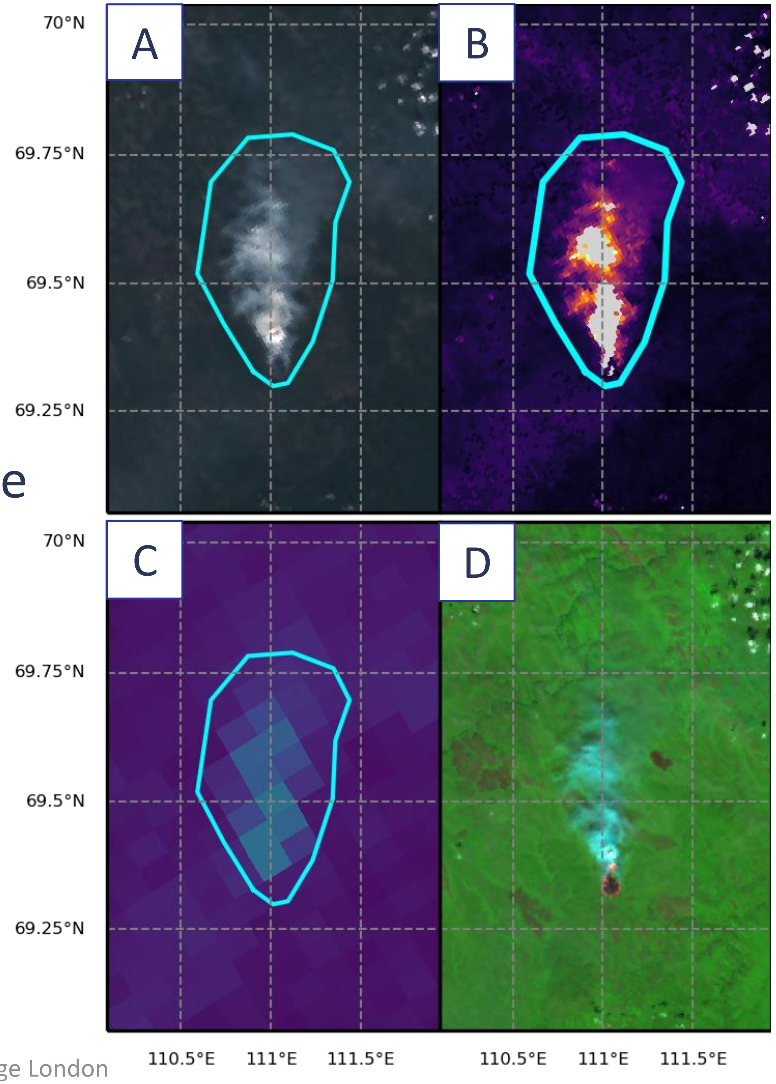

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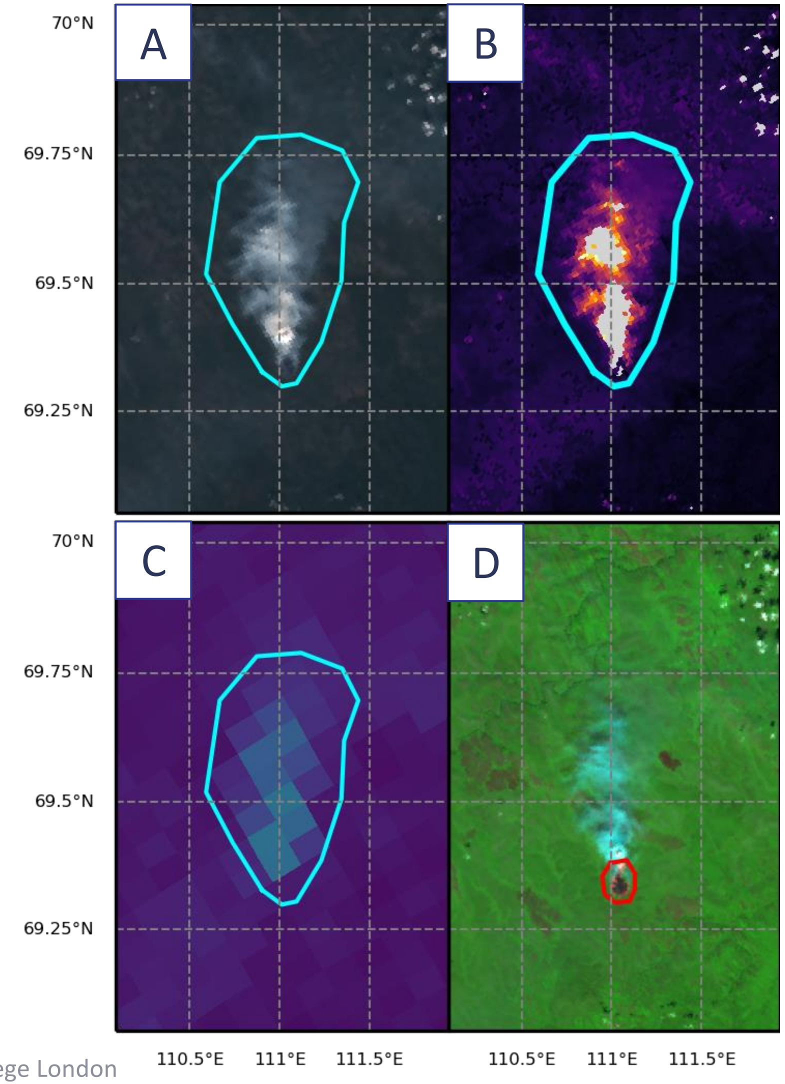
Similar Process for FRE and Biome

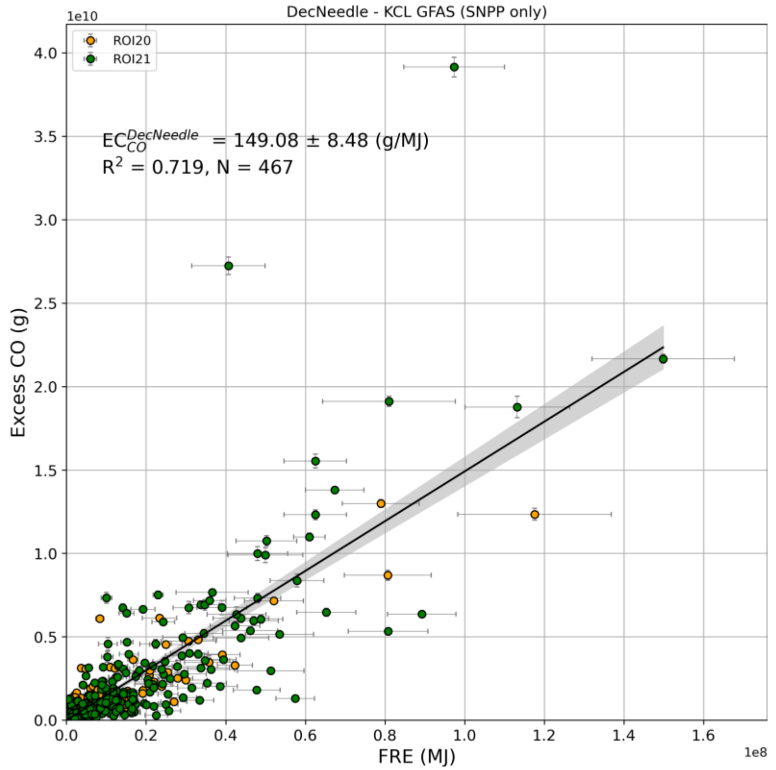
- Using False Colour Composite (D) to highlight fire activity
- Digitize Fire Area using False Colour Composite (D) and Active Fire
- Extract Hourly FRP from GFAS
  - 06:00 → Sentinel-5P overpass time
- Finding all Active Fire pixels within Fire Polygon
- ≥ 50% same biome → Dominant Biome

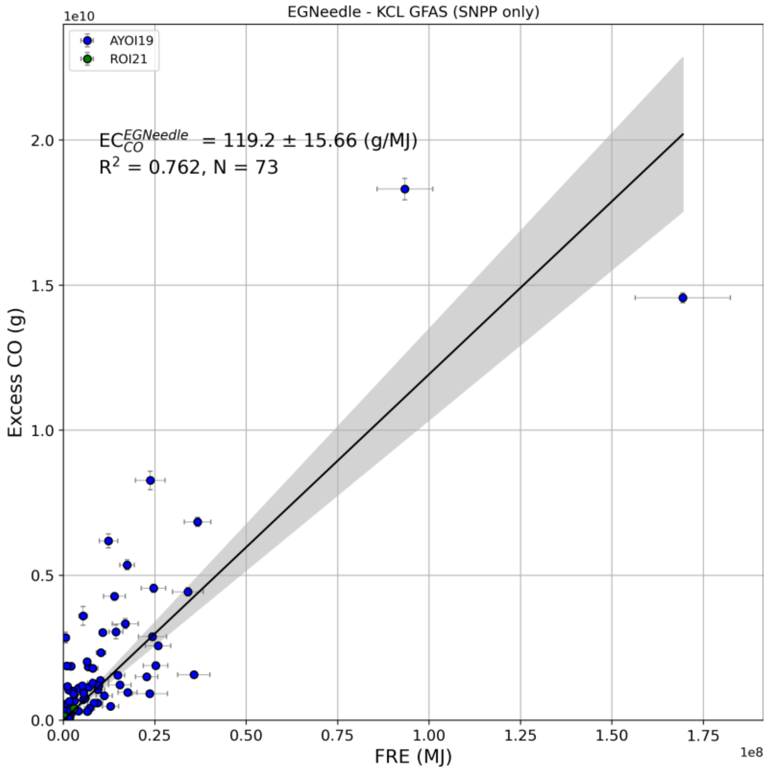


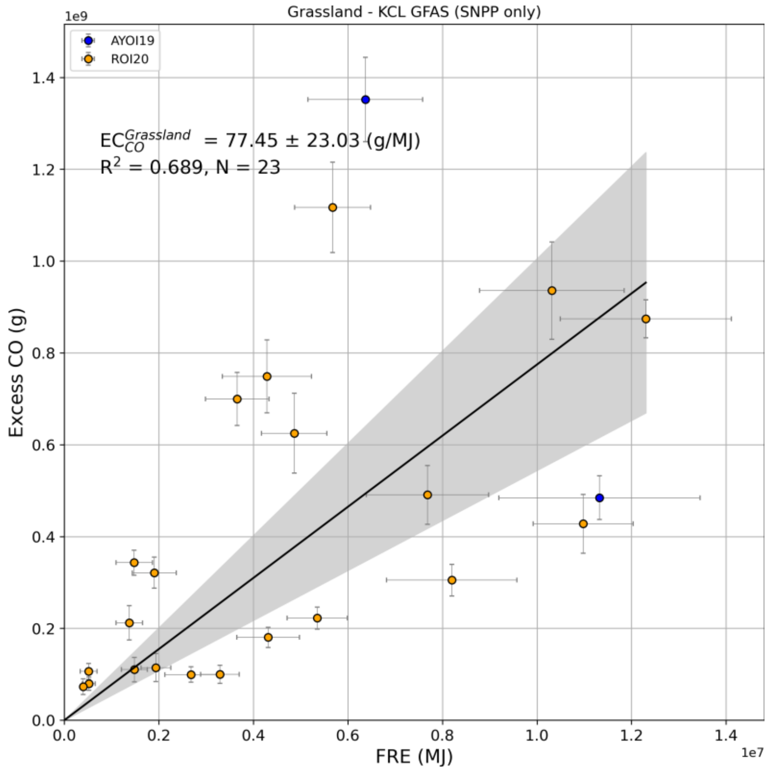
aFREM Emission Coefficient (EC_{CO}^{biome}) Calculation

EC_{CO}^{biome} relates the rate of release of CO (g.s^{-1}) to the rate of release of FRE (i.e. FRP, MW)

Grouping plumes by biome, can generate Biome Specific Emission Coefficients for CO, EC_{CO}^{biome}



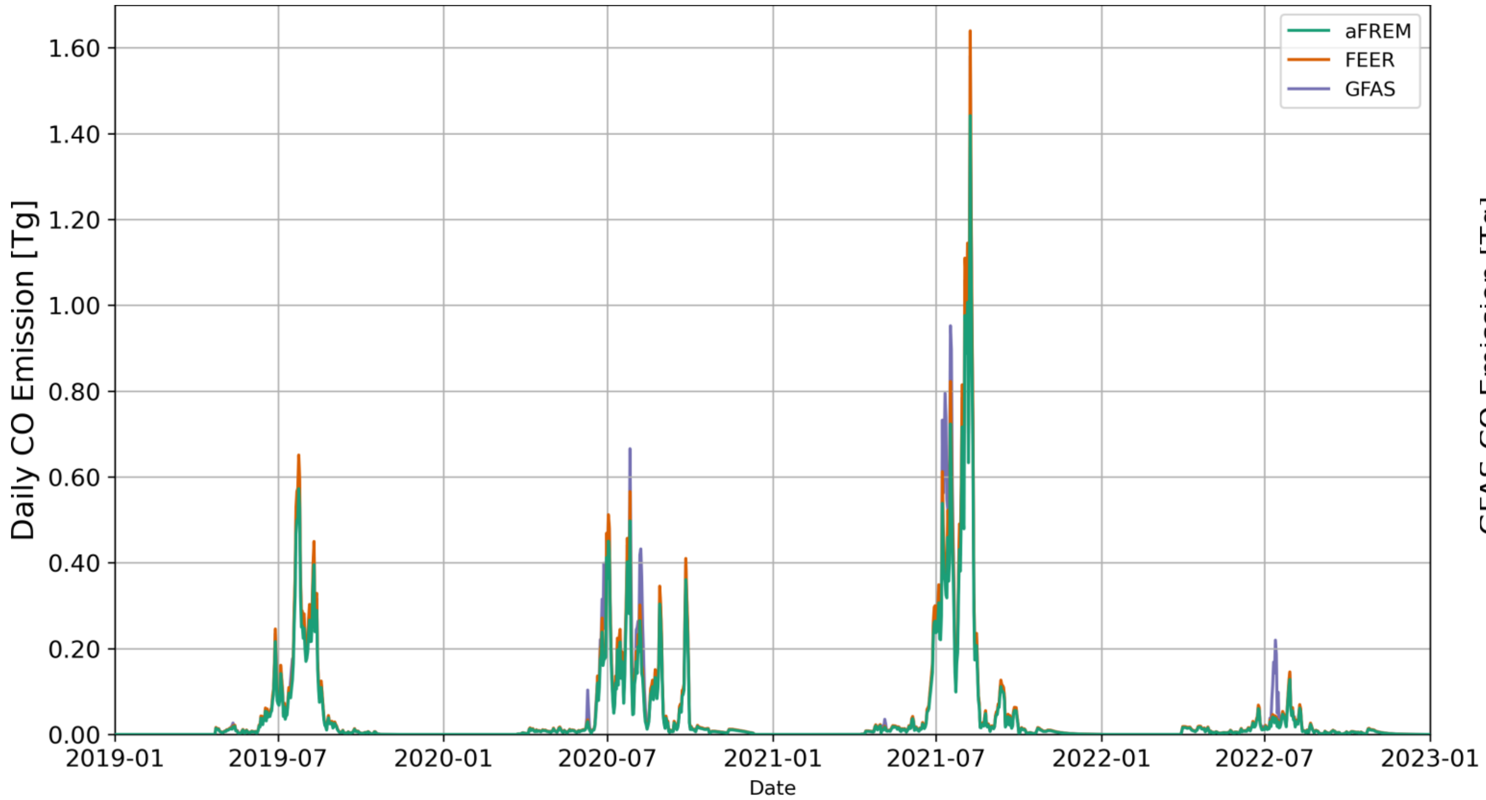


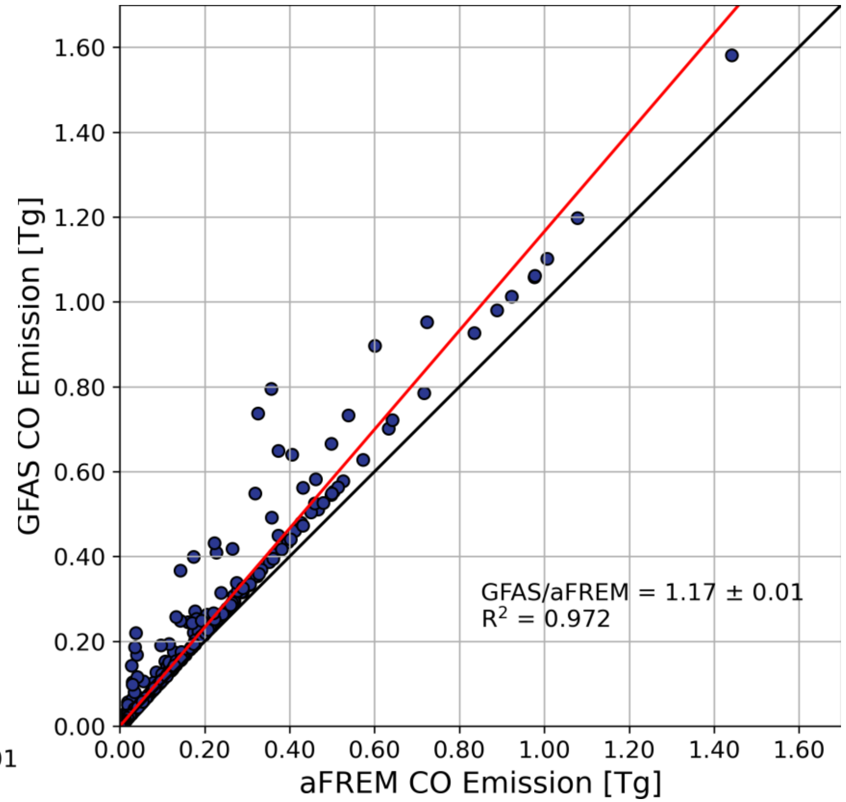


CO Emission Estimation – Deciduous Needleleaf

aFREM produces similar CO Emissions for “Deciduous Needleleaf” forest fires to existing inventories

- ~86% w.r.t GFAS, ~88% w.r.t FEER

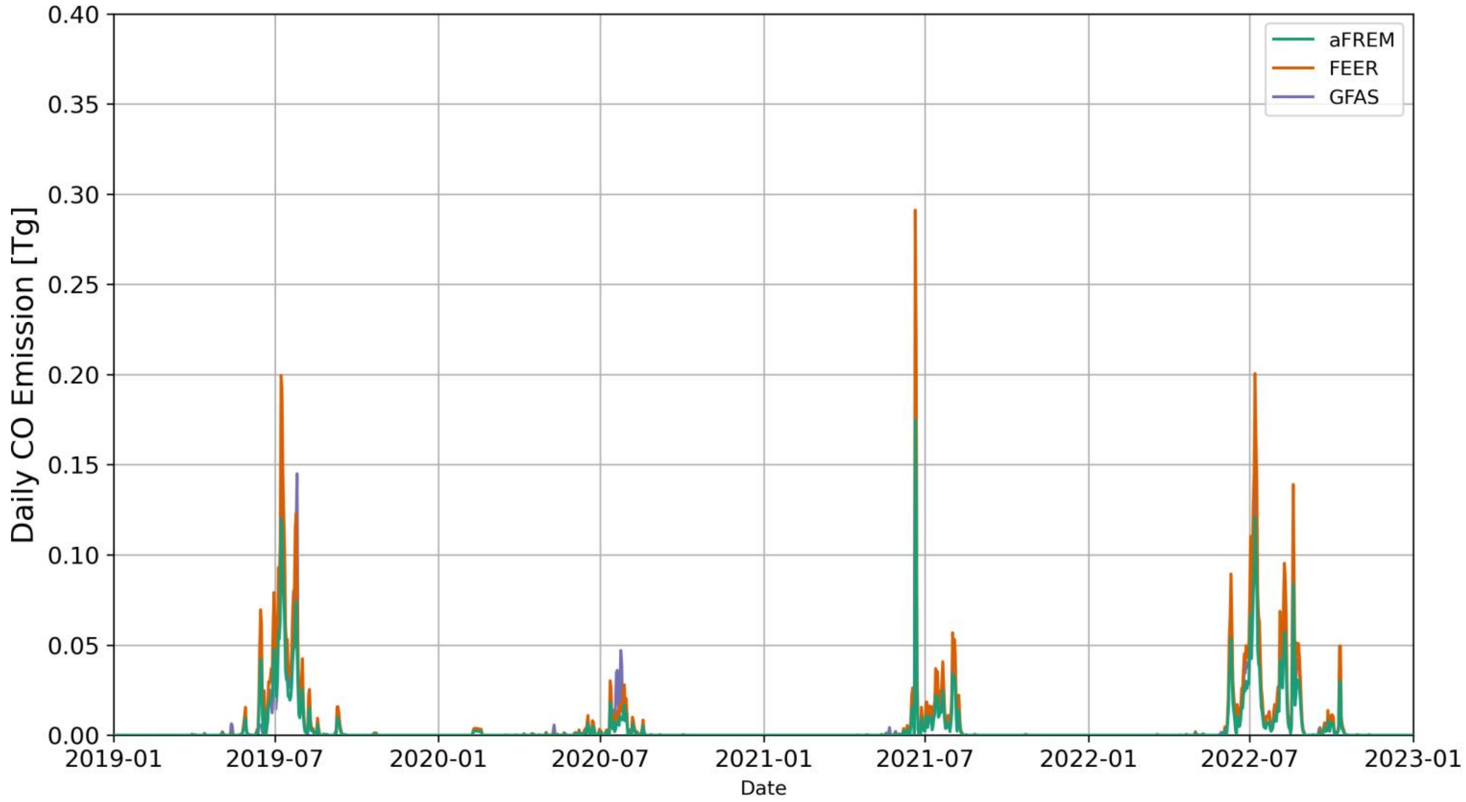


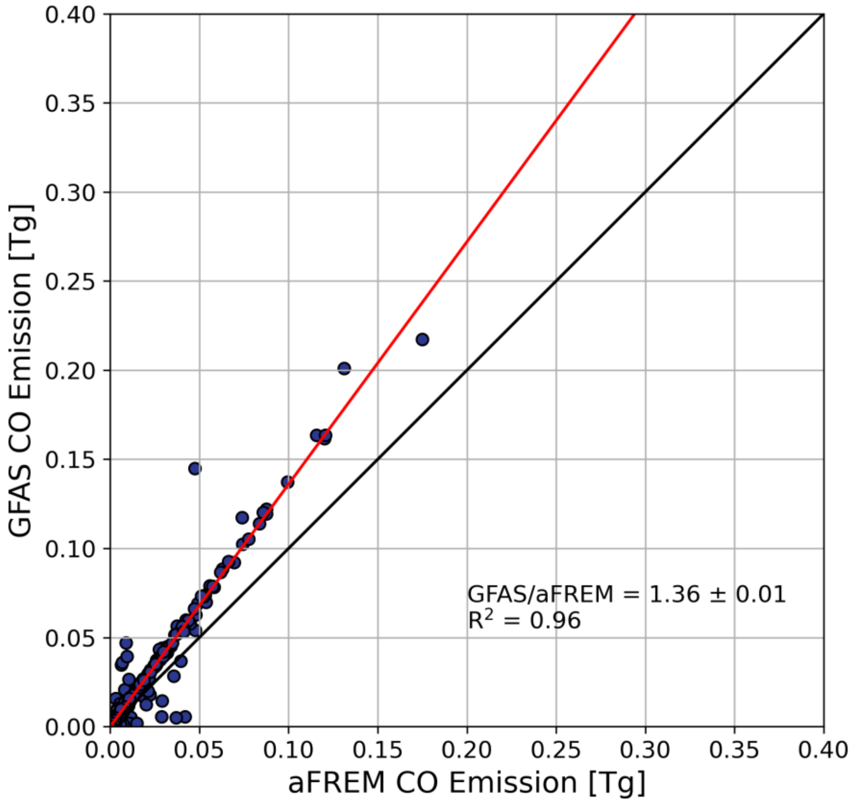


CO Emission Estimation – Evergreen Needleleaf

aFREM produces similar CO Emissions for "Evergreen Needleleaf" forest fires to existing inventories

- ~74% w.r.t GFAS, ~60% w.r.t FEER

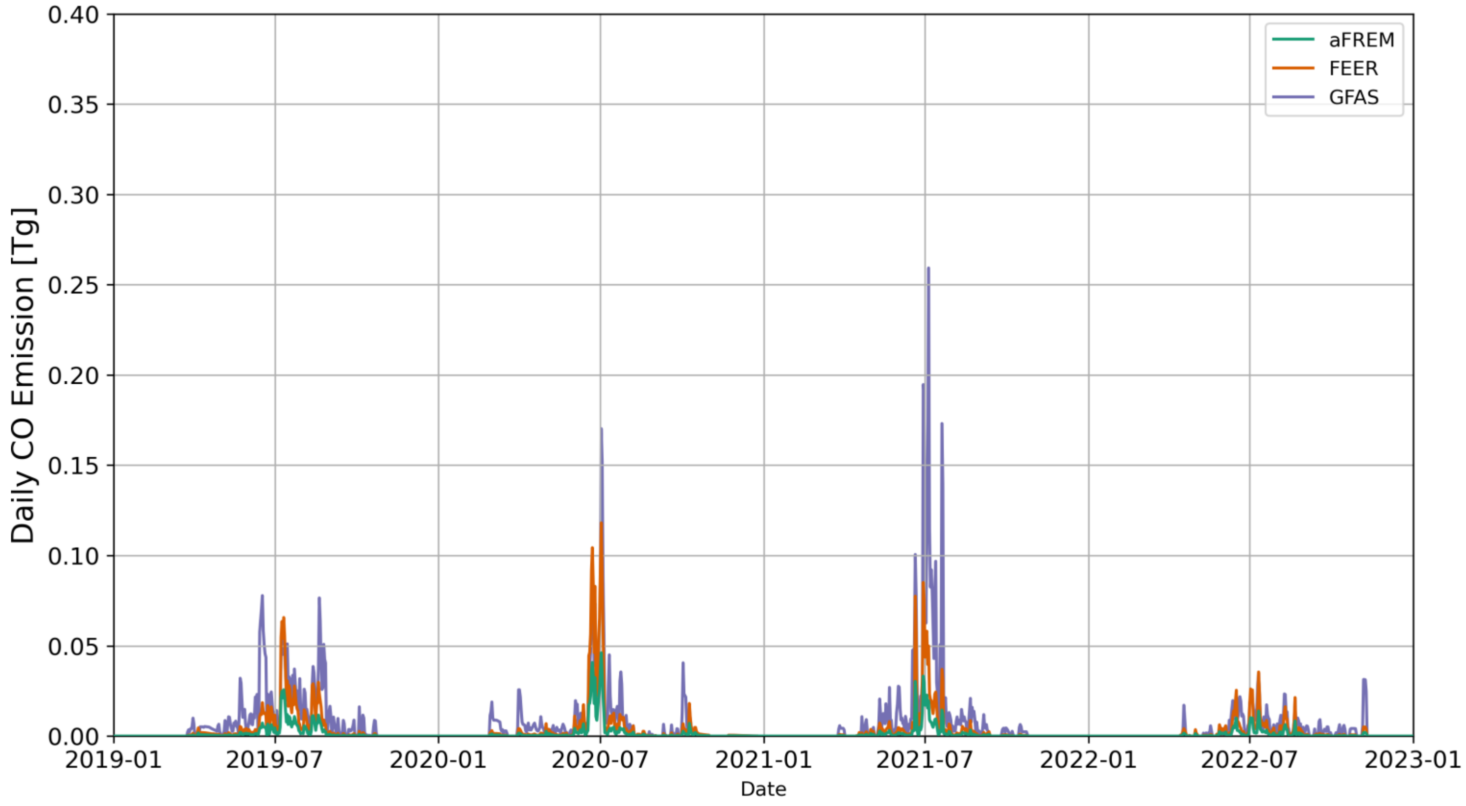


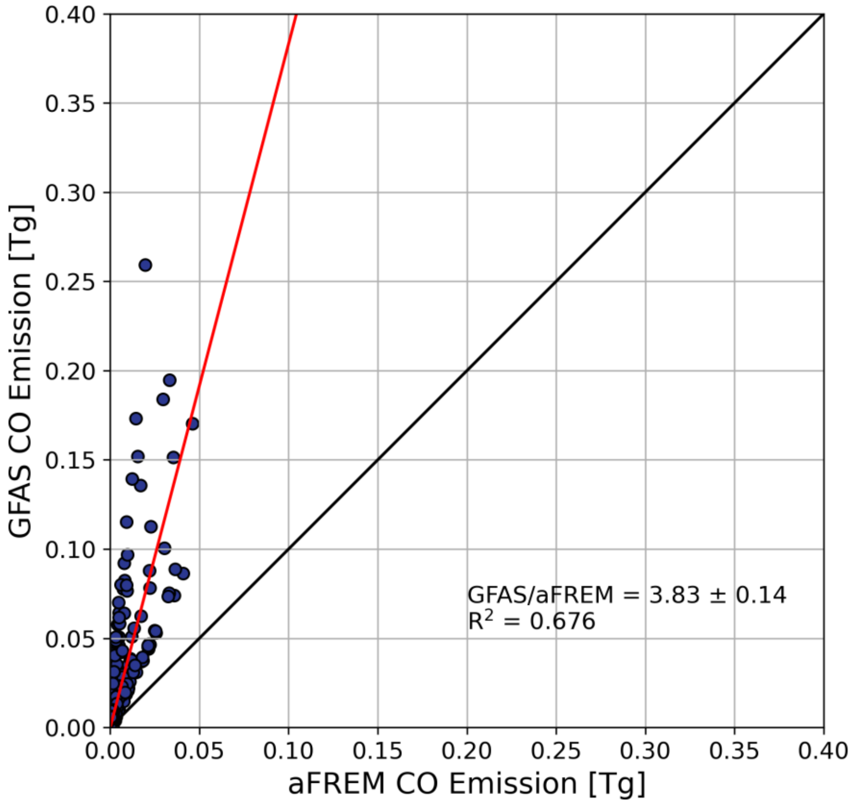


CO Emission Estimation – Grassland (inc. high latitude Tundra)

aFREM generates CO Emissions lower for “High Latitude Grassland Fires” than existing inventories

- ~26% w.r.t GFAS, ~39% w.r.t FEER





Summary and Next Steps

Introduced the aFREM approach, directly linking CO Emission rate to FRP for polar orbiters

- Digitizing Plumes and Fire Activity using VIIRS
- Calculating EC_{CO}^{biome} for Evergreen and Deciduous Needleleaf Forest, and Grasslands (Tundra)
- Estimates of Daily CO emissions compared those of FEER and GFAS

Abstract

Next Steps

- Completing Analysis of COI23 (193 additional plume observations)
- Full Timeseries Analysis (2019 – 2023)
- Impact of peat vs non-peat on EC_{CO}^{biome}
- Full Carbon Emissions estimation from the CO values
- Monthly Comparison with GFED

KCL Research Group

Thanks for listening!