[Thermal]
Earth Observation of Landscape Fires

Presented by M. Wooster

EO Science for a changing planet

www.nceo.ac.uk

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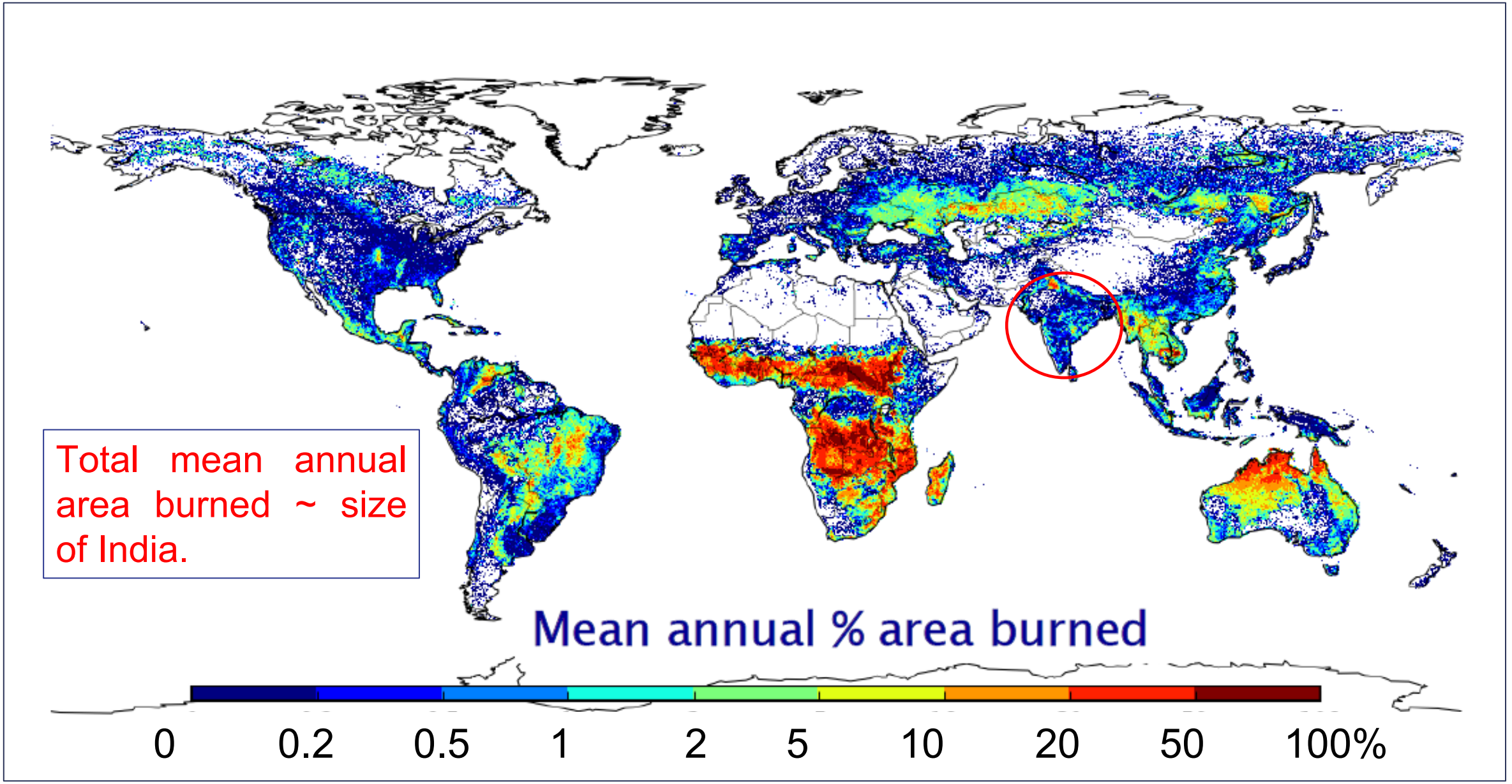
National Centre for Earth Observation

NATURAL ENVIRONMENT RESEARCH COUNCIL

KING'S College LONDON

UKRI Natural Environment Research Council

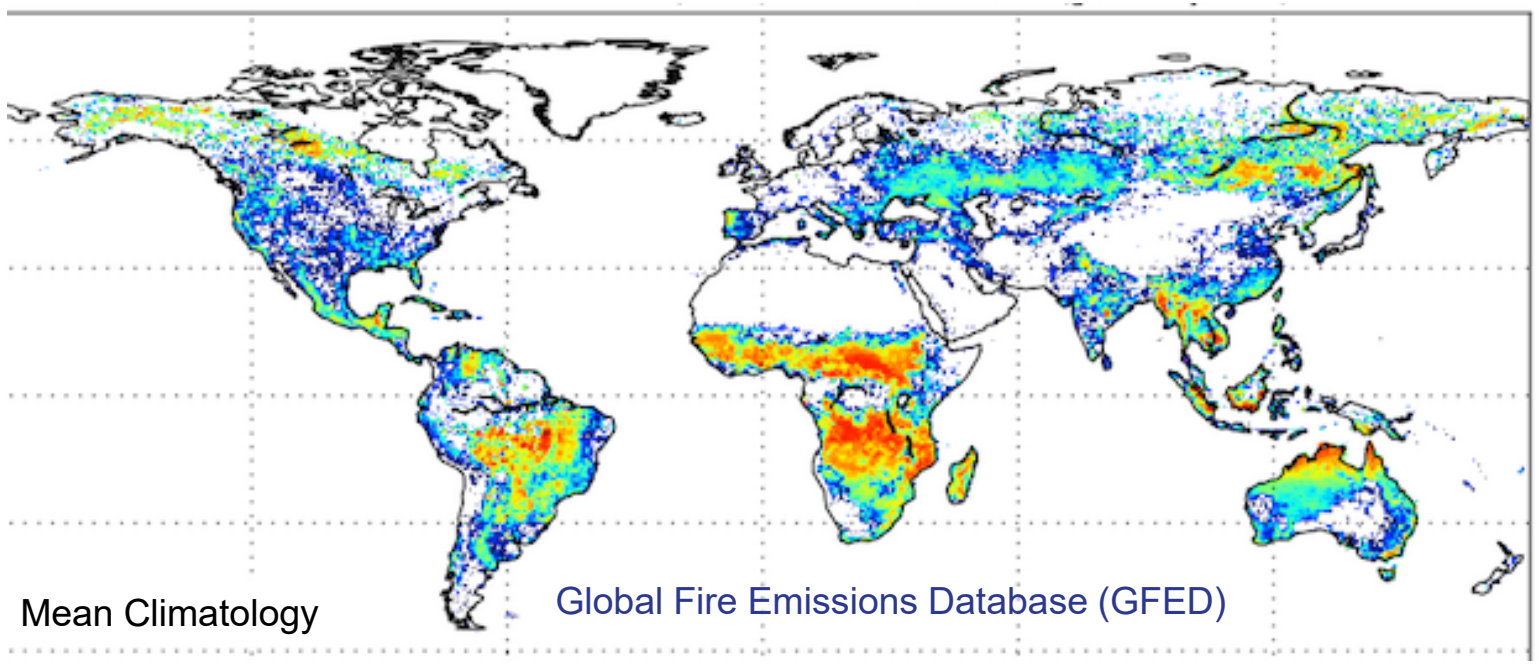
Global Burned Area [MODIS]

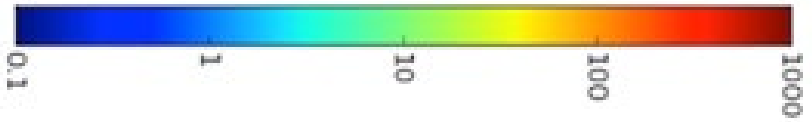


$$\text{Emissions}_{\text{Species}} = \text{Burned Area} \times \text{Fuel Load} \times \text{Combustion Completeness} \times EF_{\text{Species}}$$

Fuel burned per unit area

Total fuel burned





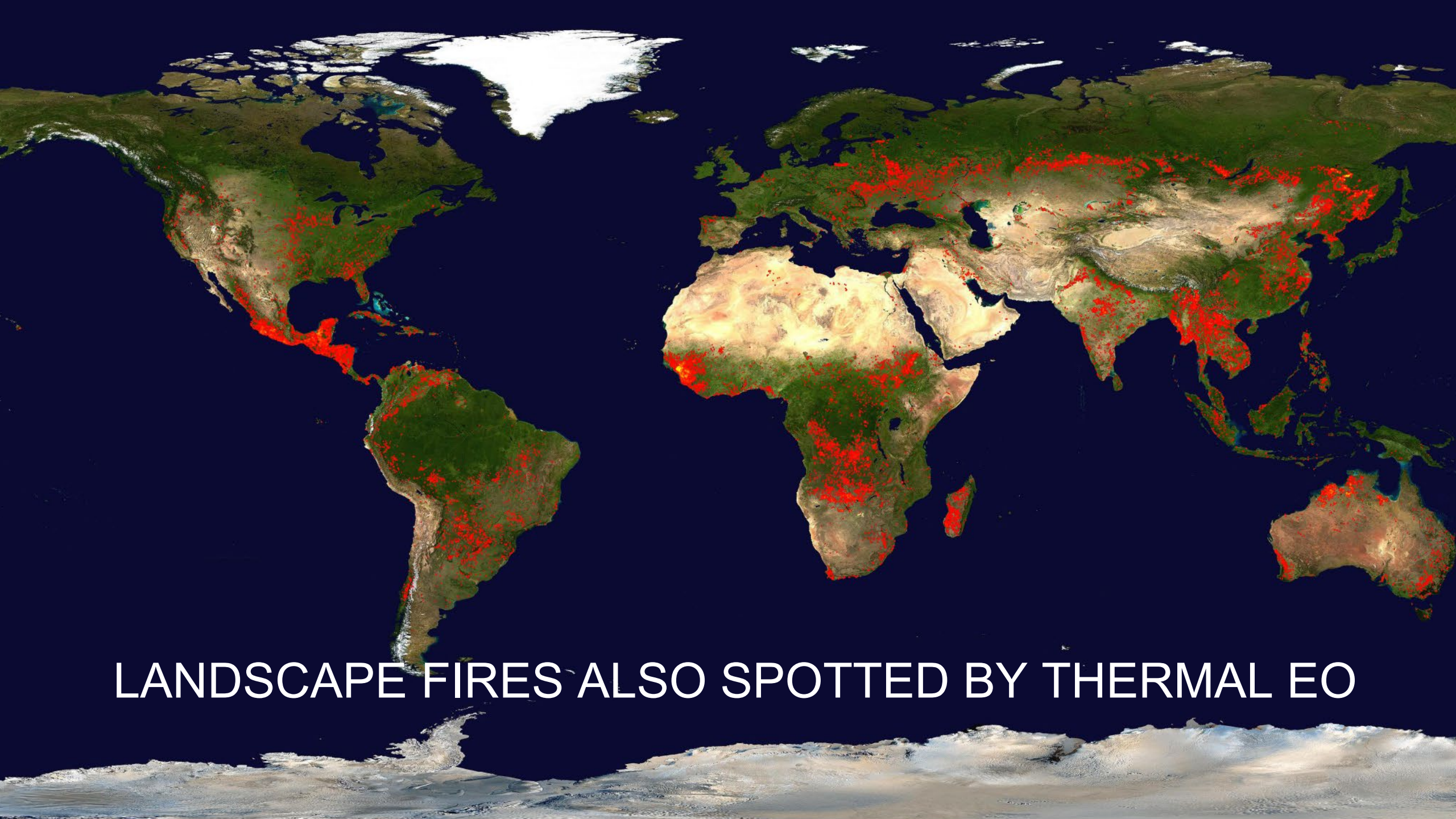
Emitted Carbon (g m^{-2} yr^{-1})

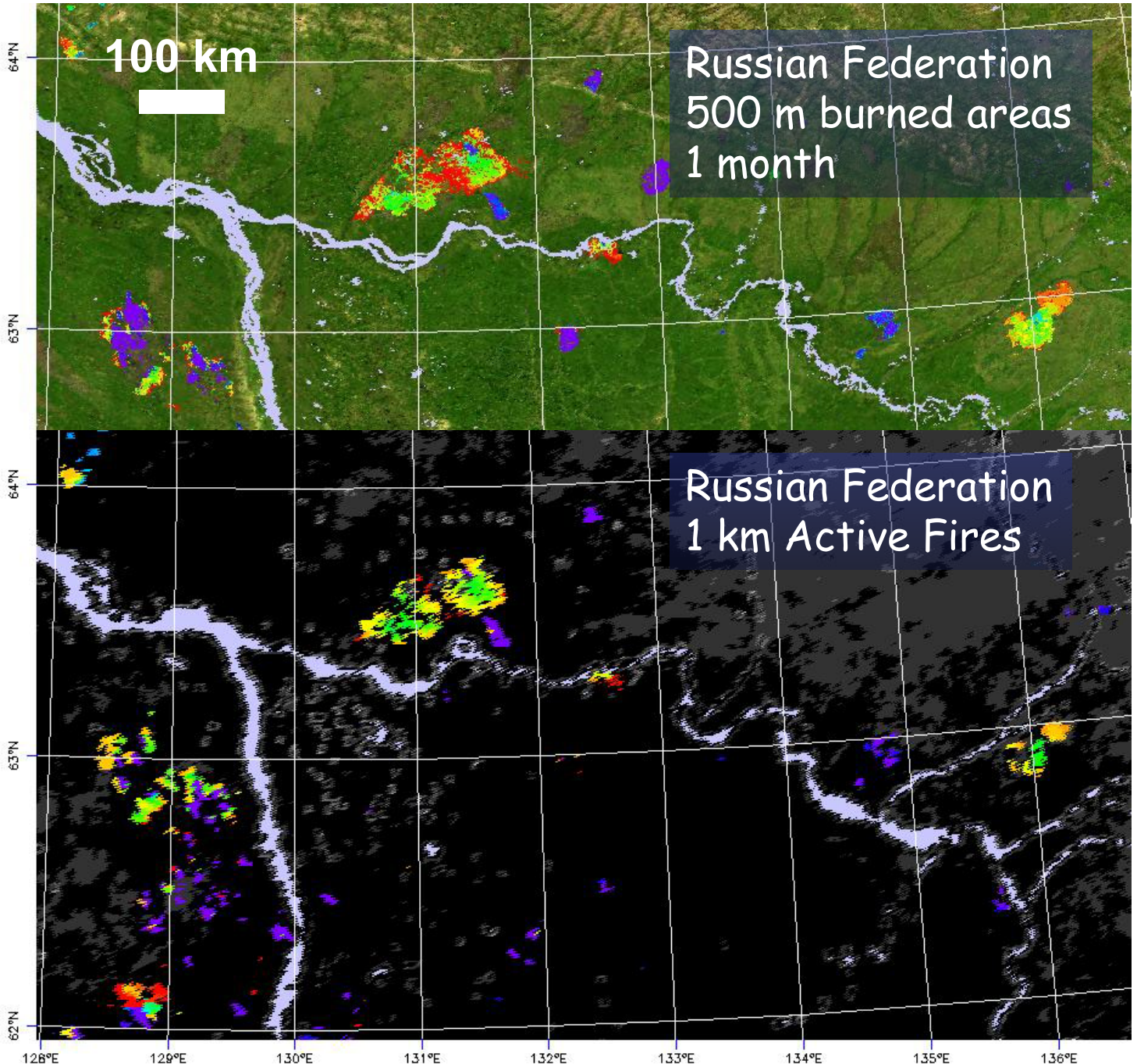
Non Real Time

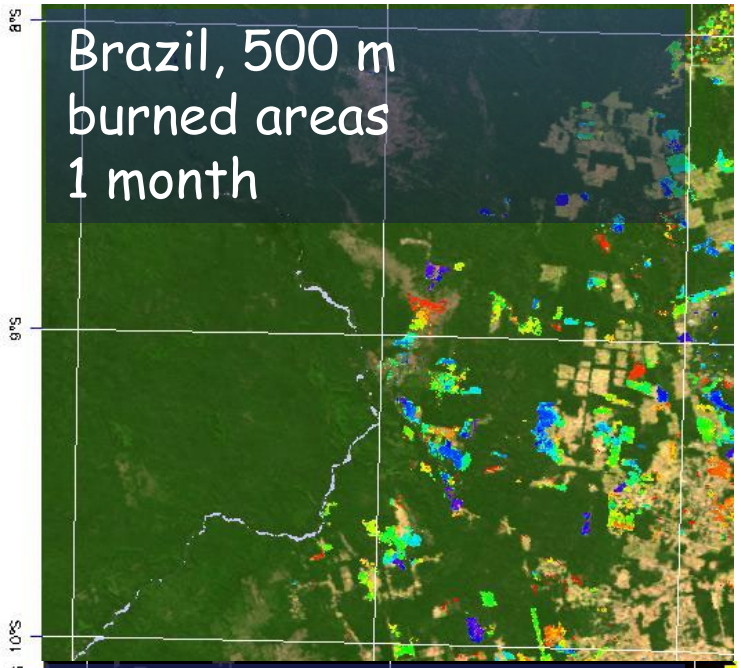
Smoke Constituents

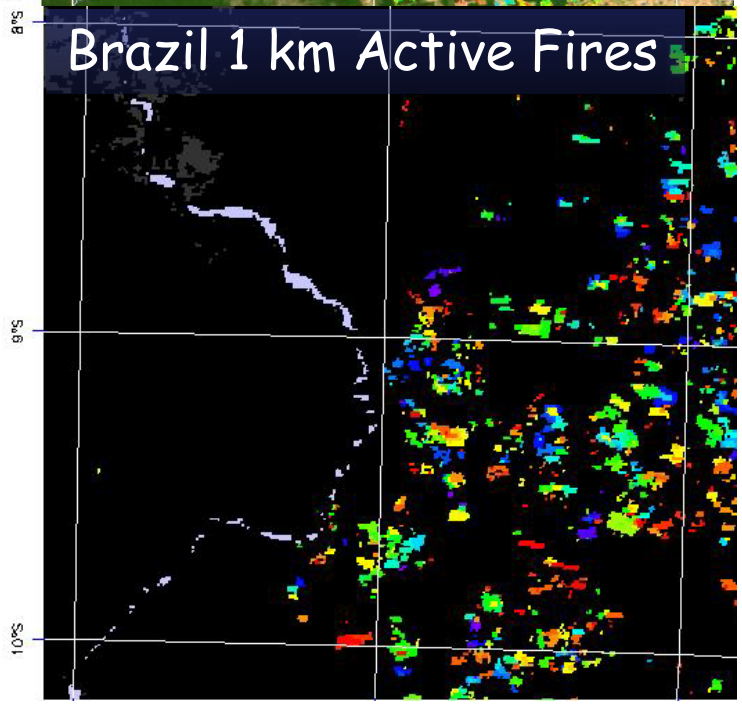
	Emissions $TgYr^{-1}$	% of Global Total
CO	300 – 600	30 – 45%
BC	5 – 7	45 – 65%
CH_4	15 – 30	3 – 6%
VOC	20 – 40	10 – 20%
H_2	5 – 15	15 – 40%
SO_2	2 – 8	2 – 8%
NO_x	6–10 ($TgN\ yr^{-1}$)	12 – 20%

- Global C emissions: ~2.3 Pg C/yr
- ~ ¼ occurs at deforestation frontier


LANDSCAPE FIRES ALSO SPOTTED BY THERMAL EO

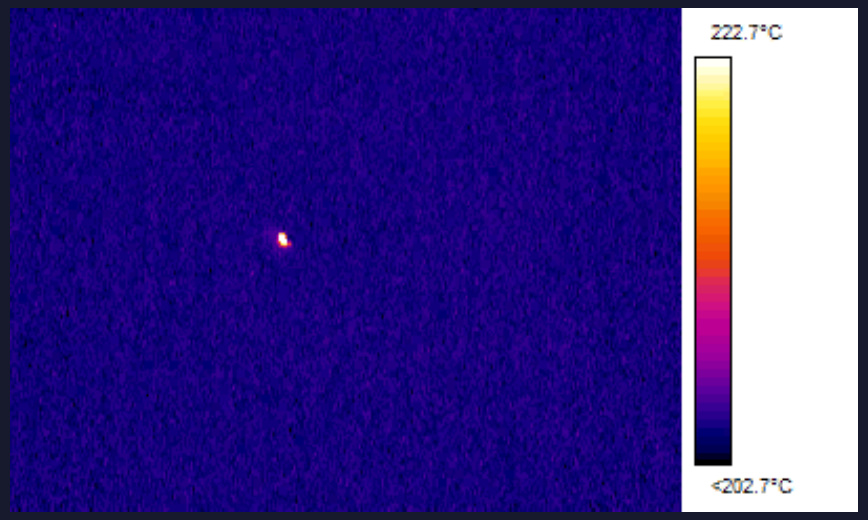




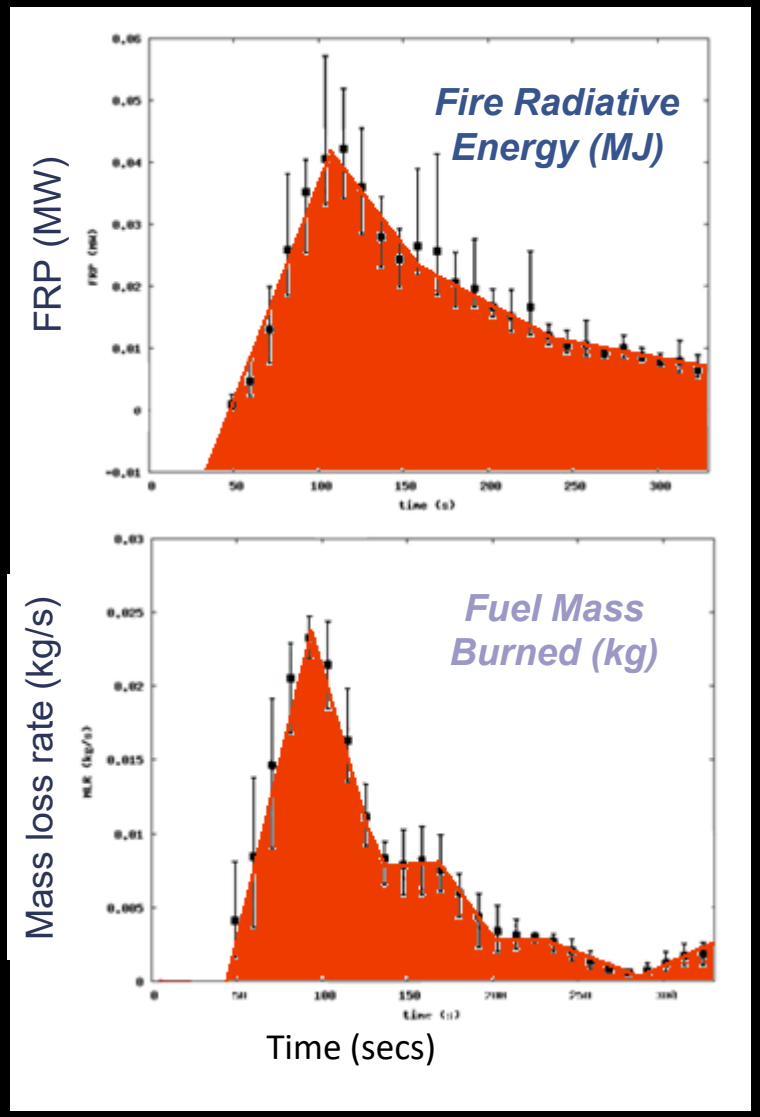


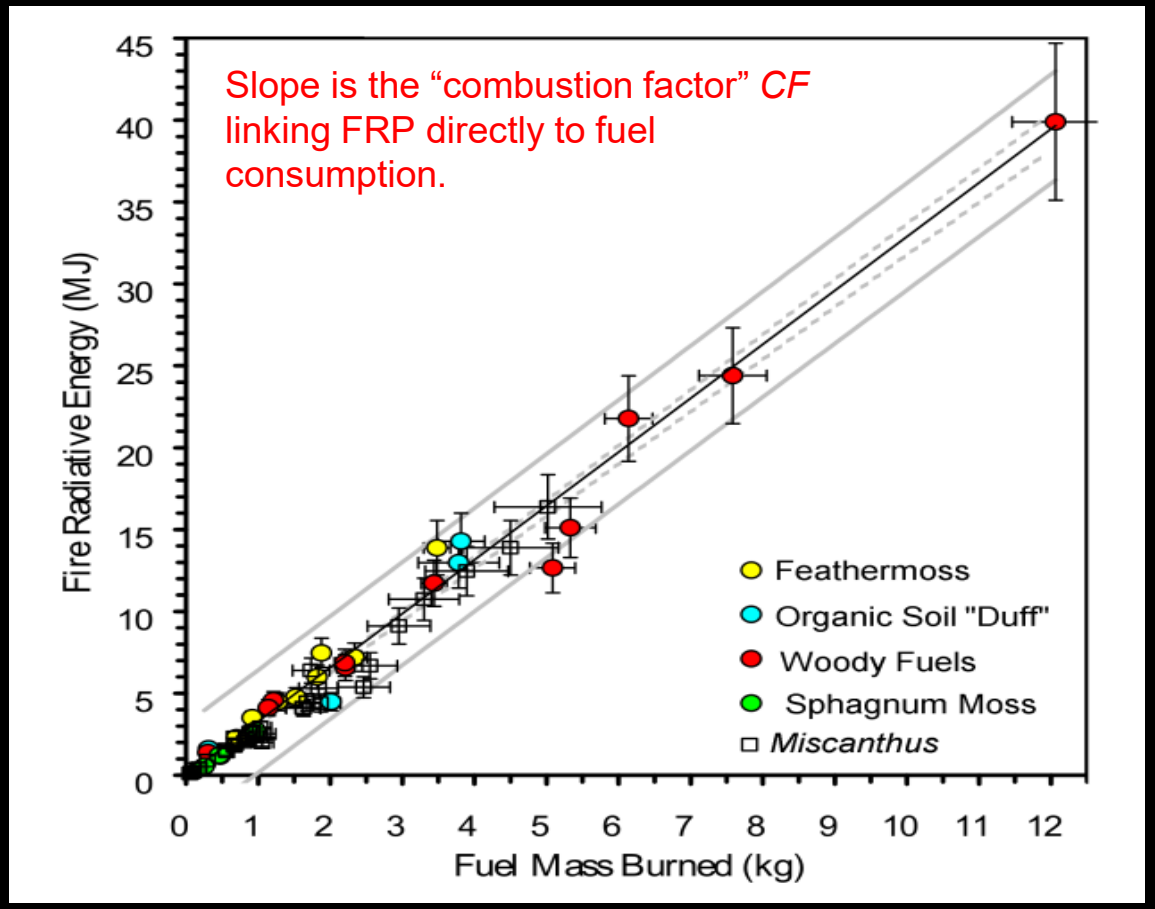
Roy et al. (2010)

Fire Radiative Power to Fuel Consumption



Fire Radiative Energy & Fuel Consumption



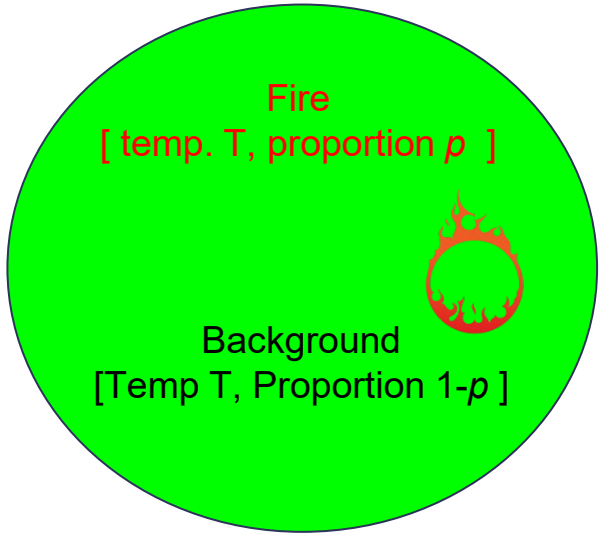


Fuel Consumption = CF × Σ FRP

Theoretically ~ constant

FRP now part of the Global Climate Observing System Essential Climate Variables

Fires Give Differential Spectral Radiance Increase with Temperature at 4µm and 11µm

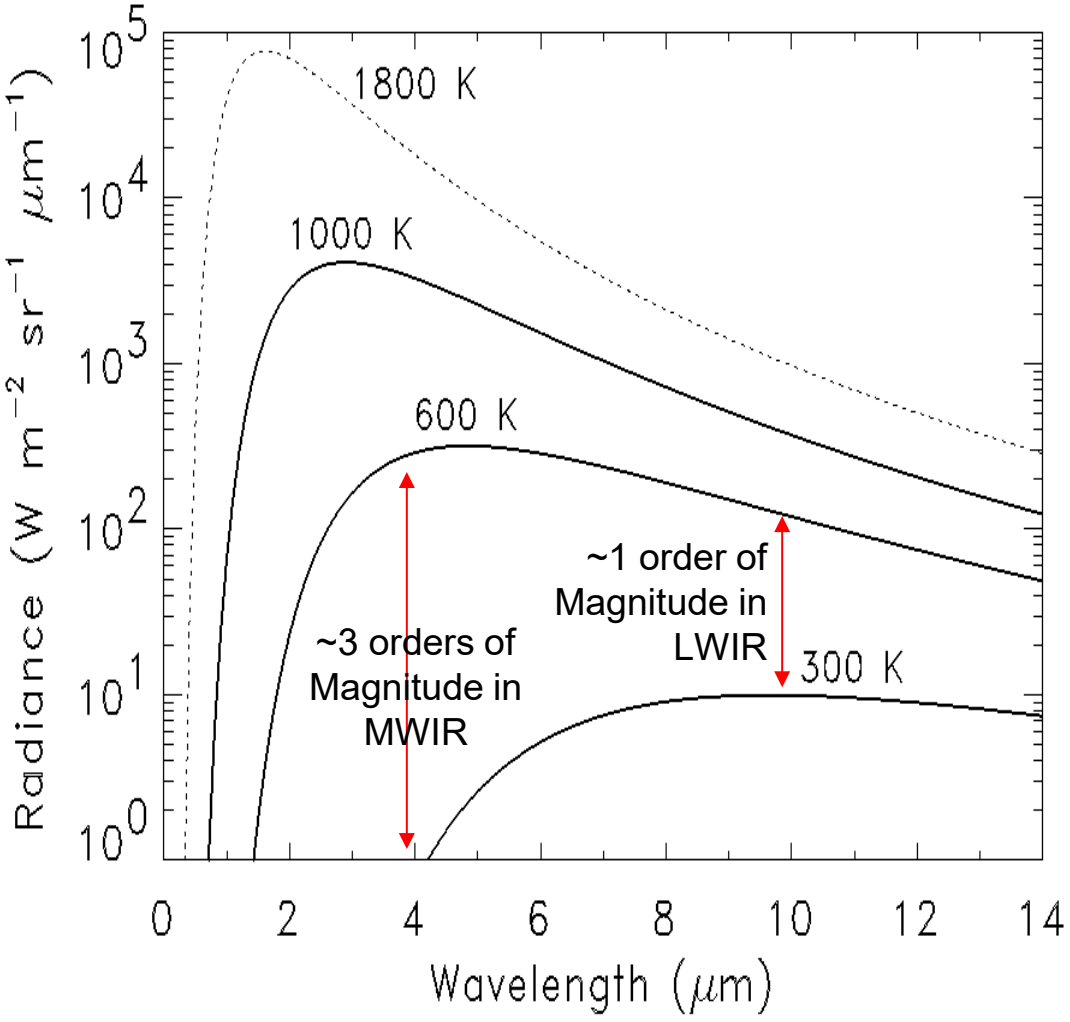


Ground Pixel Coverage
e.g. 1 km Thermal IR Pixel

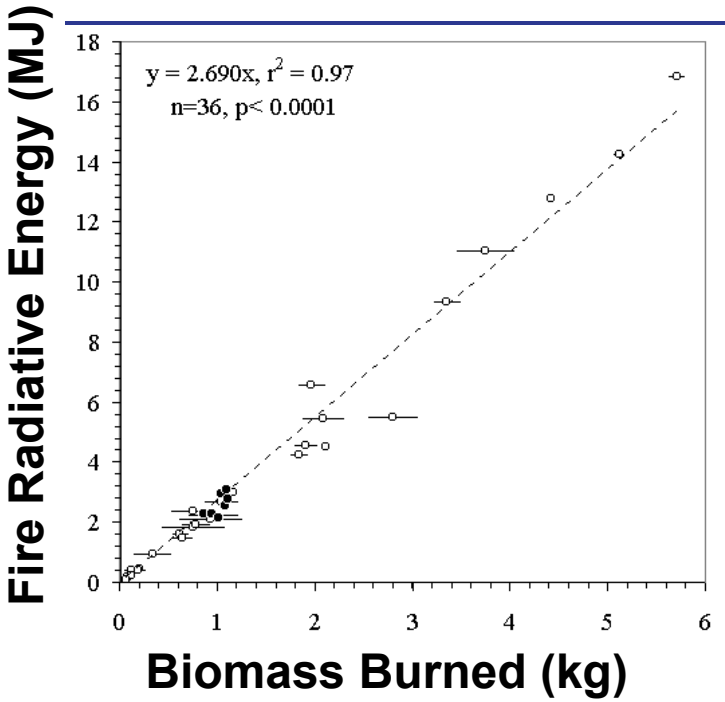
Planck's Radiation Law

$$L(\lambda,T)=\frac{C_1}{\lambda^5\left(\exp\left(\frac{C_2}{\lambda T}\right)-1\right)}$$

λ wavelength (m)
T temperature (K)
L spectral radiance ($W.m^{-2}.sr^{-1}.m^{-1}$)
$C_1 = 2\pi hc^2$ $W.m^2$
$C_2 = hc/k_B$ m.K

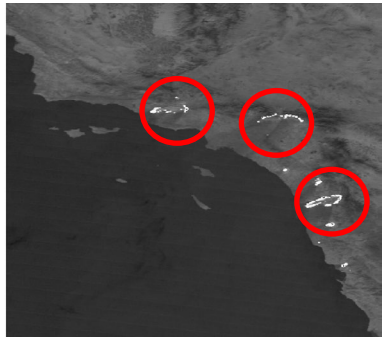


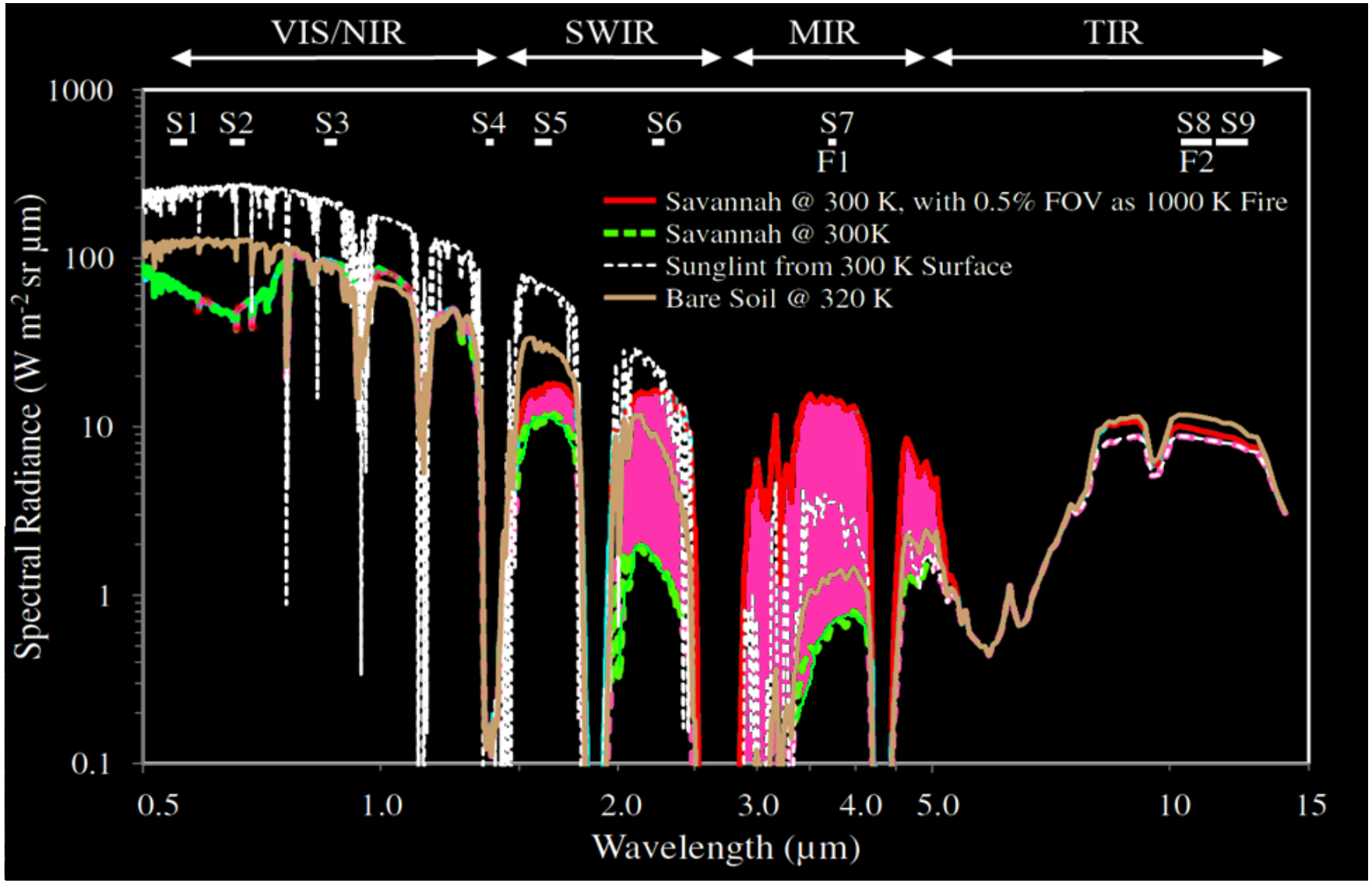
Radiative Transfer of Active Fire Detection



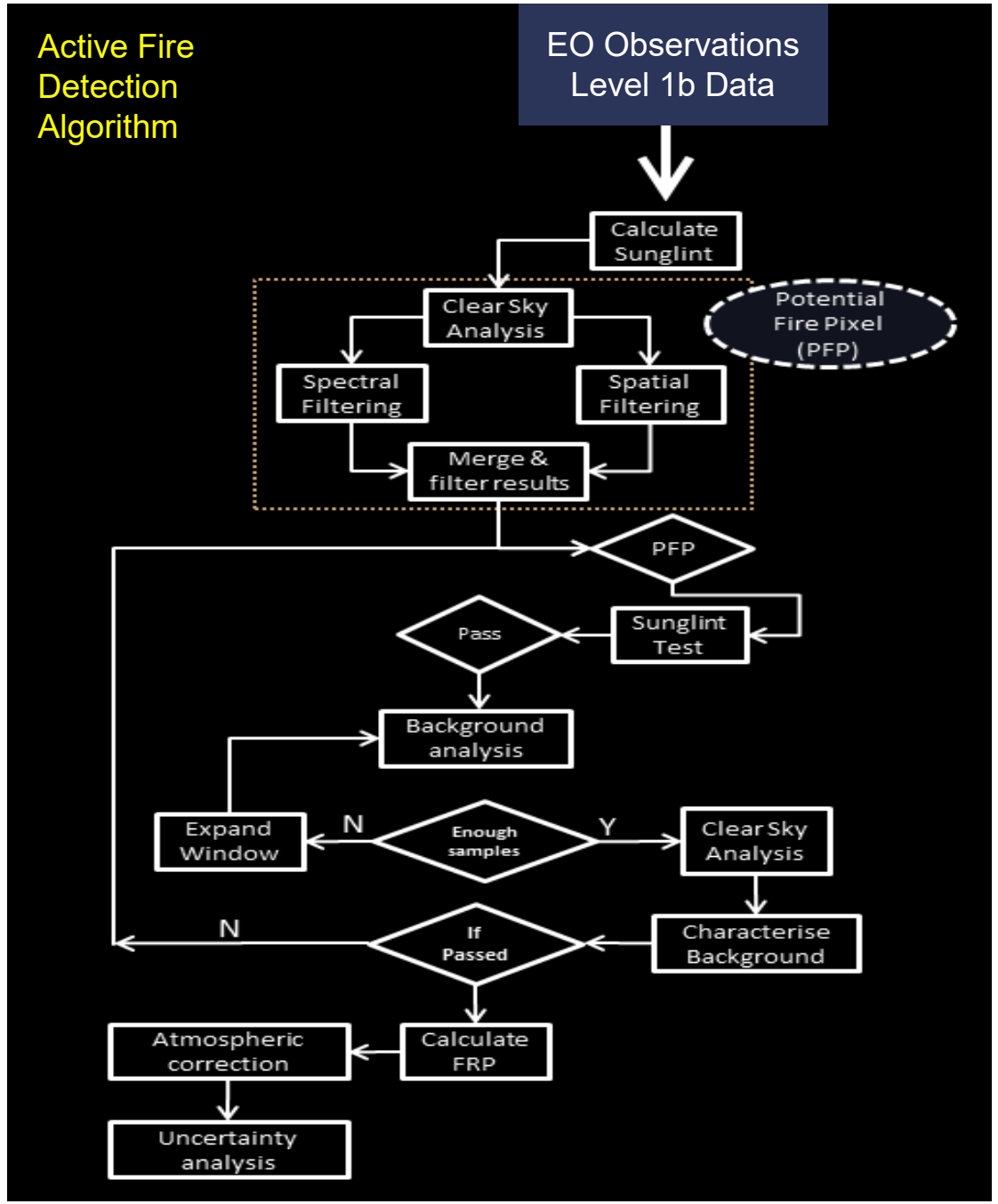
RGB

MWIR
(penetrates smoke)



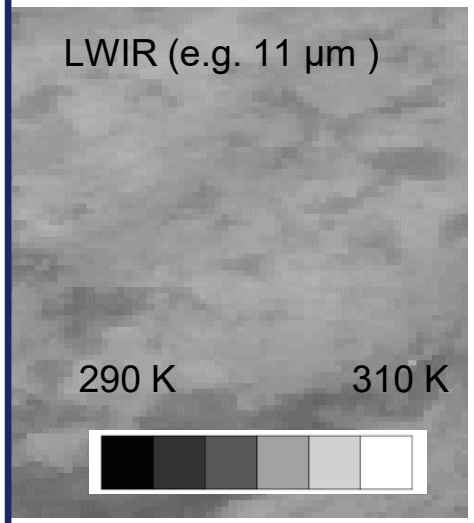


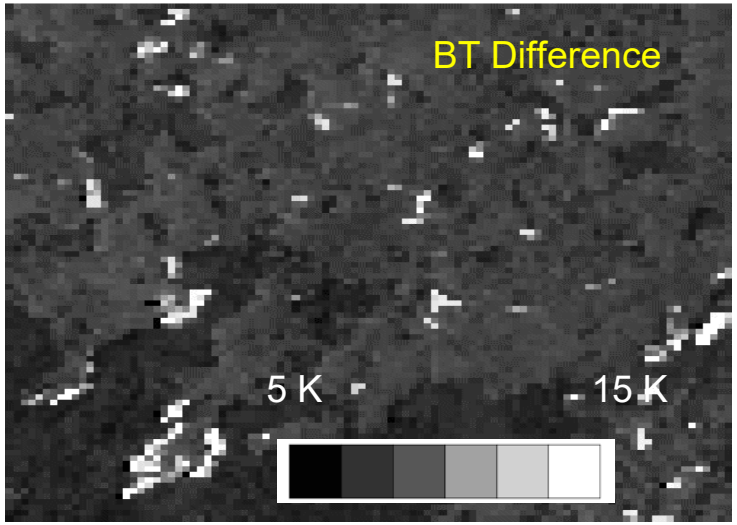
Active Fire Detection Algorithm

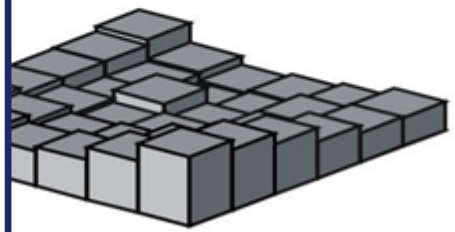


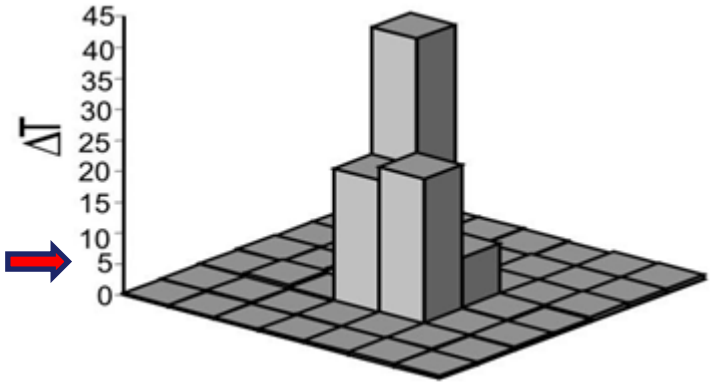
$$T = \frac{c_2}{\lambda \ln\left[\left(\frac{C_1}{\pi L_\lambda \lambda^5}\right)+1\right]}$$

Brightness Temperature [Kelvin]

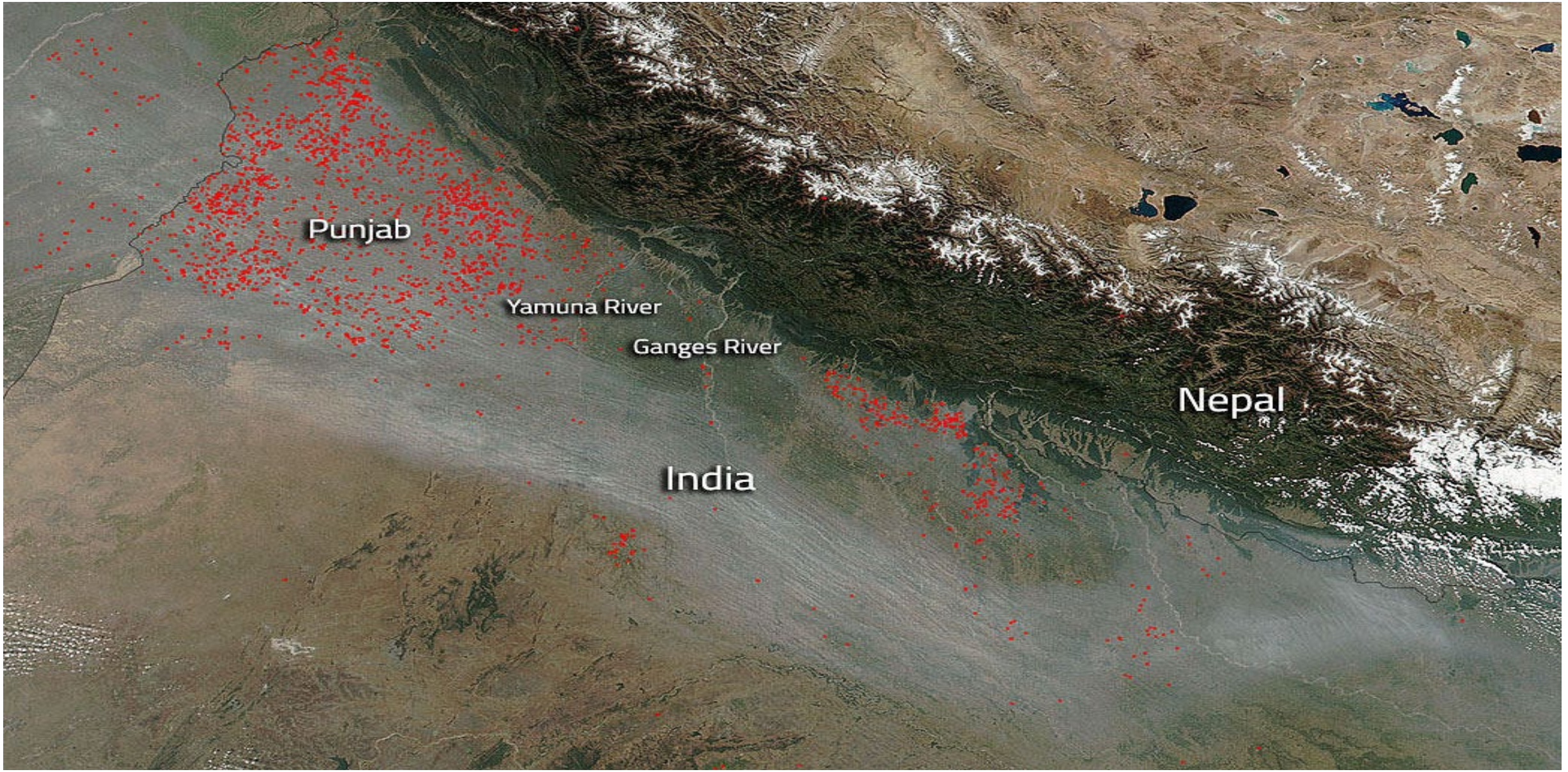








Challenge 1 – Fire Detectability (Scales with Pixel Area)



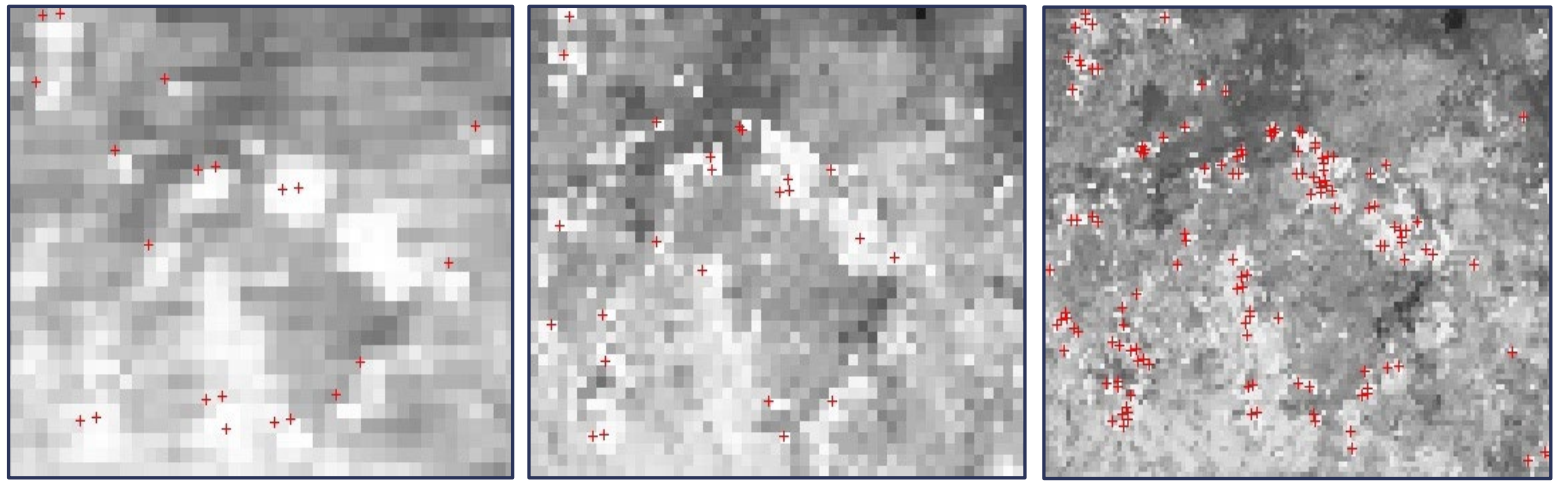
Mitigation: Small Pixels & Limit Pixel Growth

Aqua MODIS (1000 m)

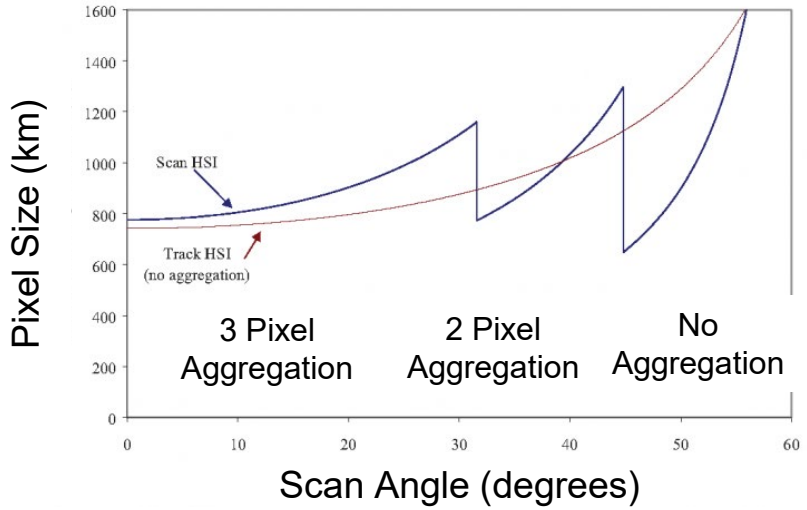
VIIRS-M band (750 m)

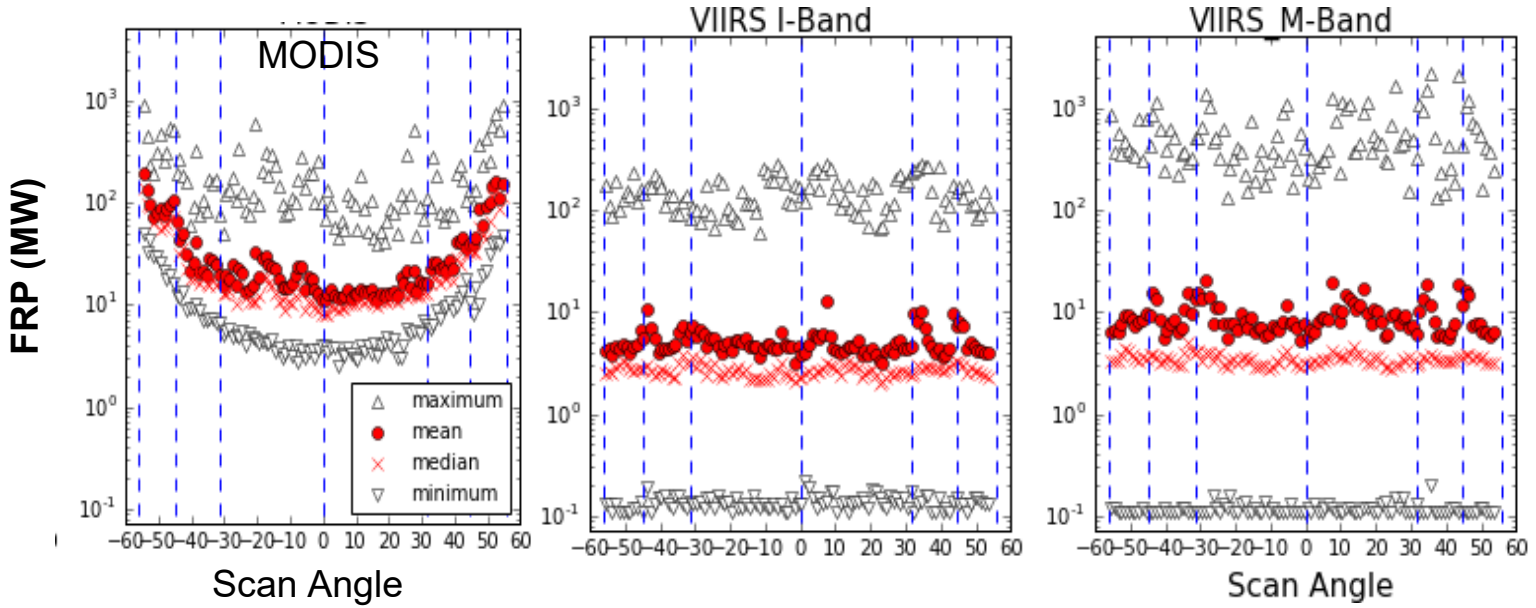
VIIRS-I band (375 m)

red = AF detection

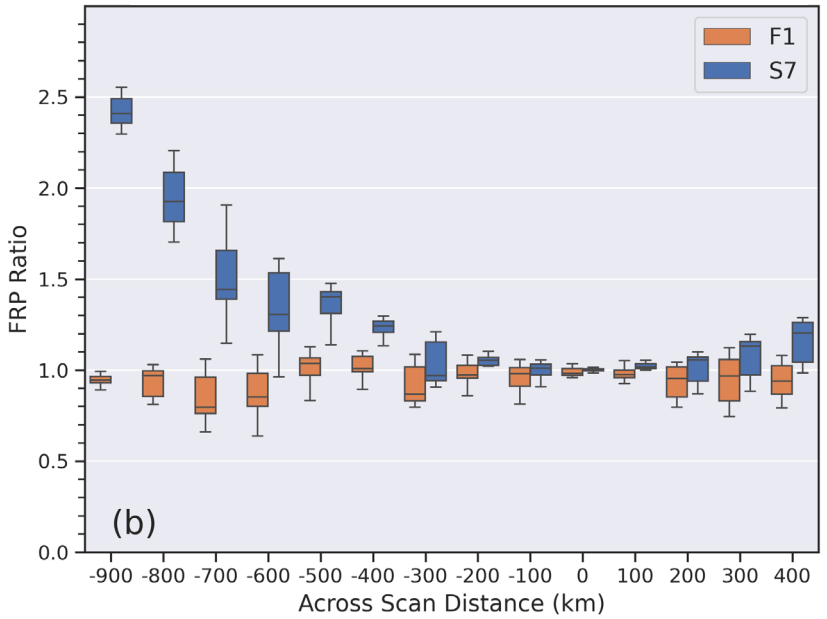


VIIRS Across Scan Pixel Growth

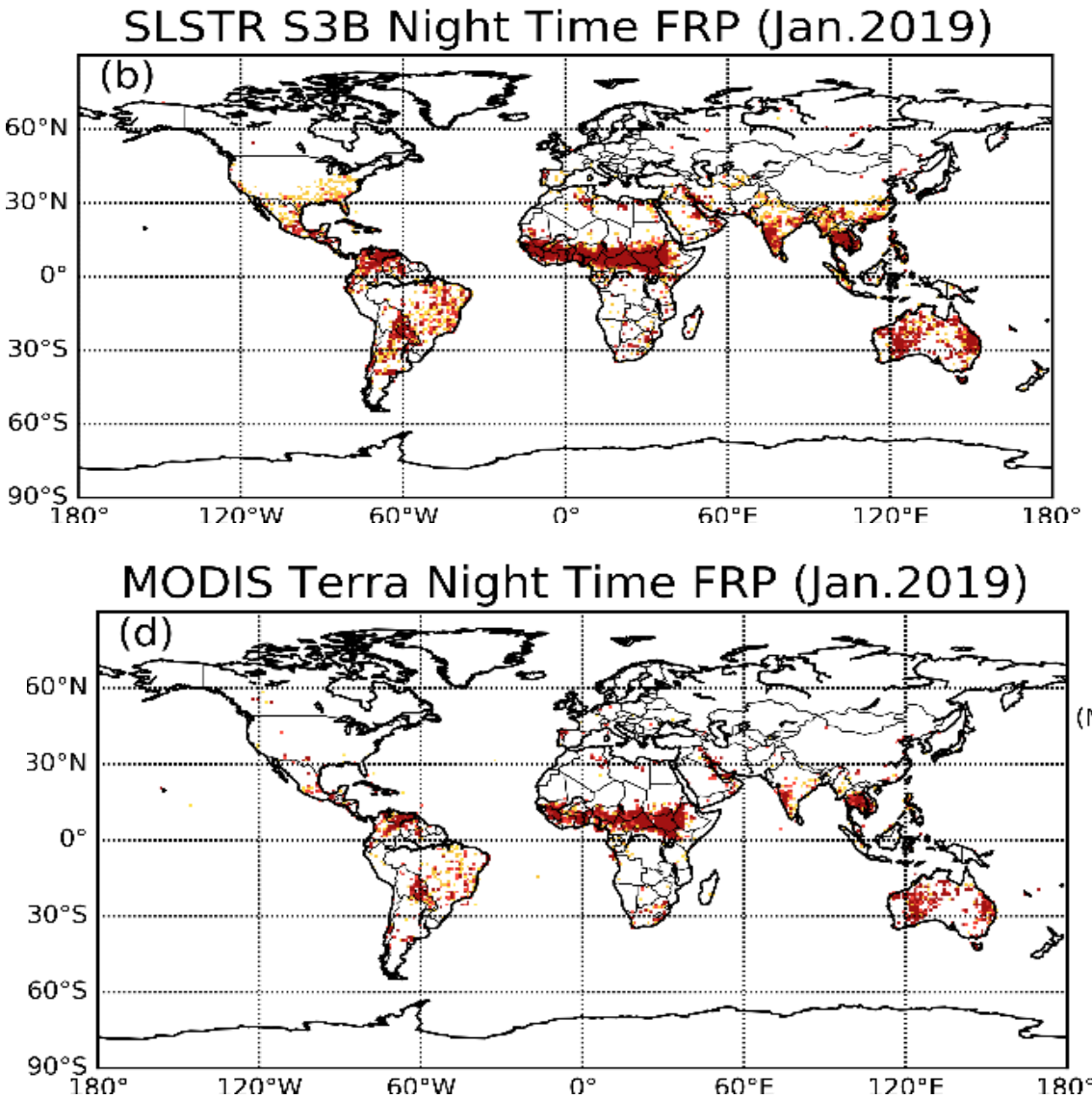


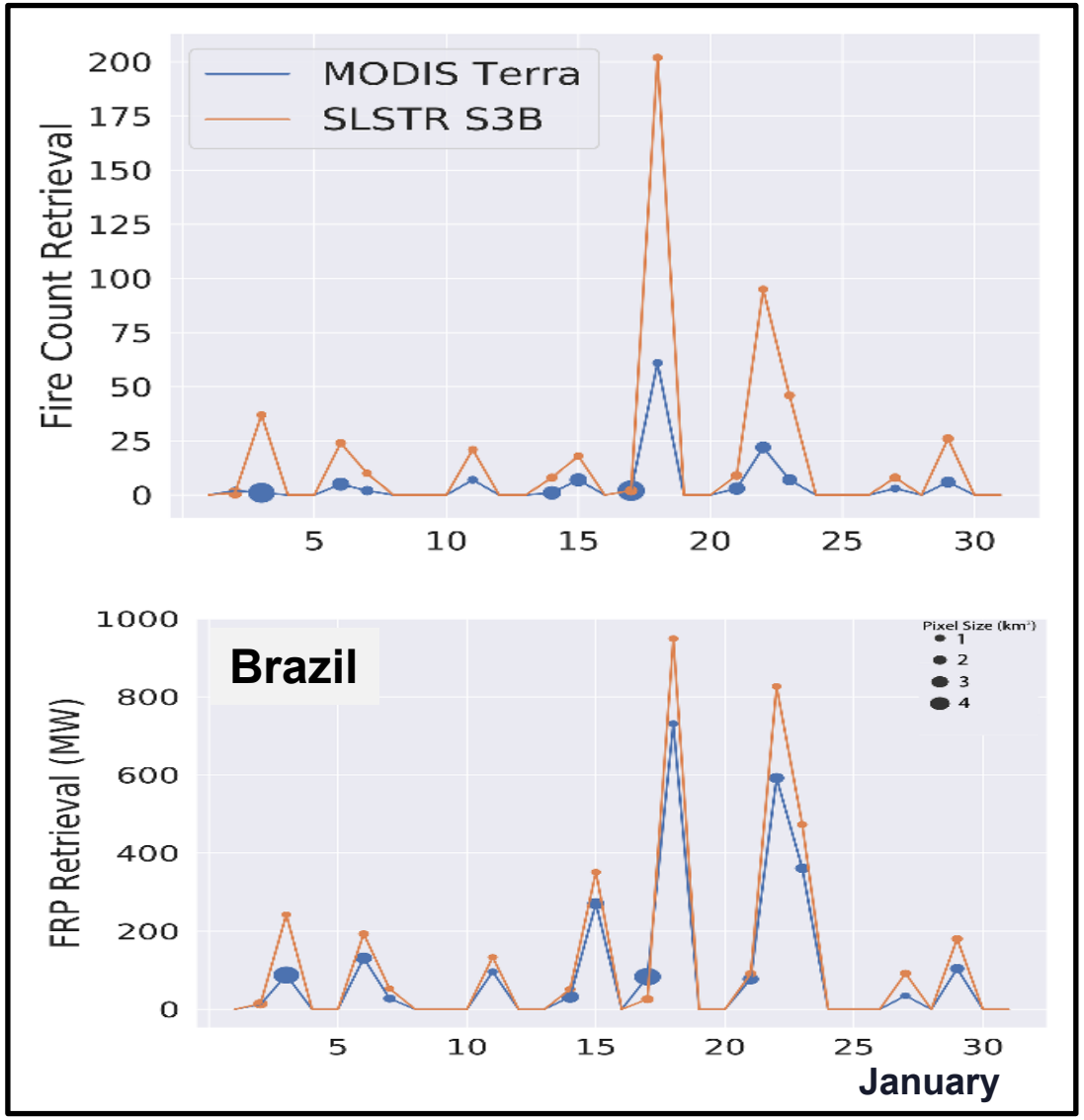


SLSTR Pixel Growth Impact on FRP



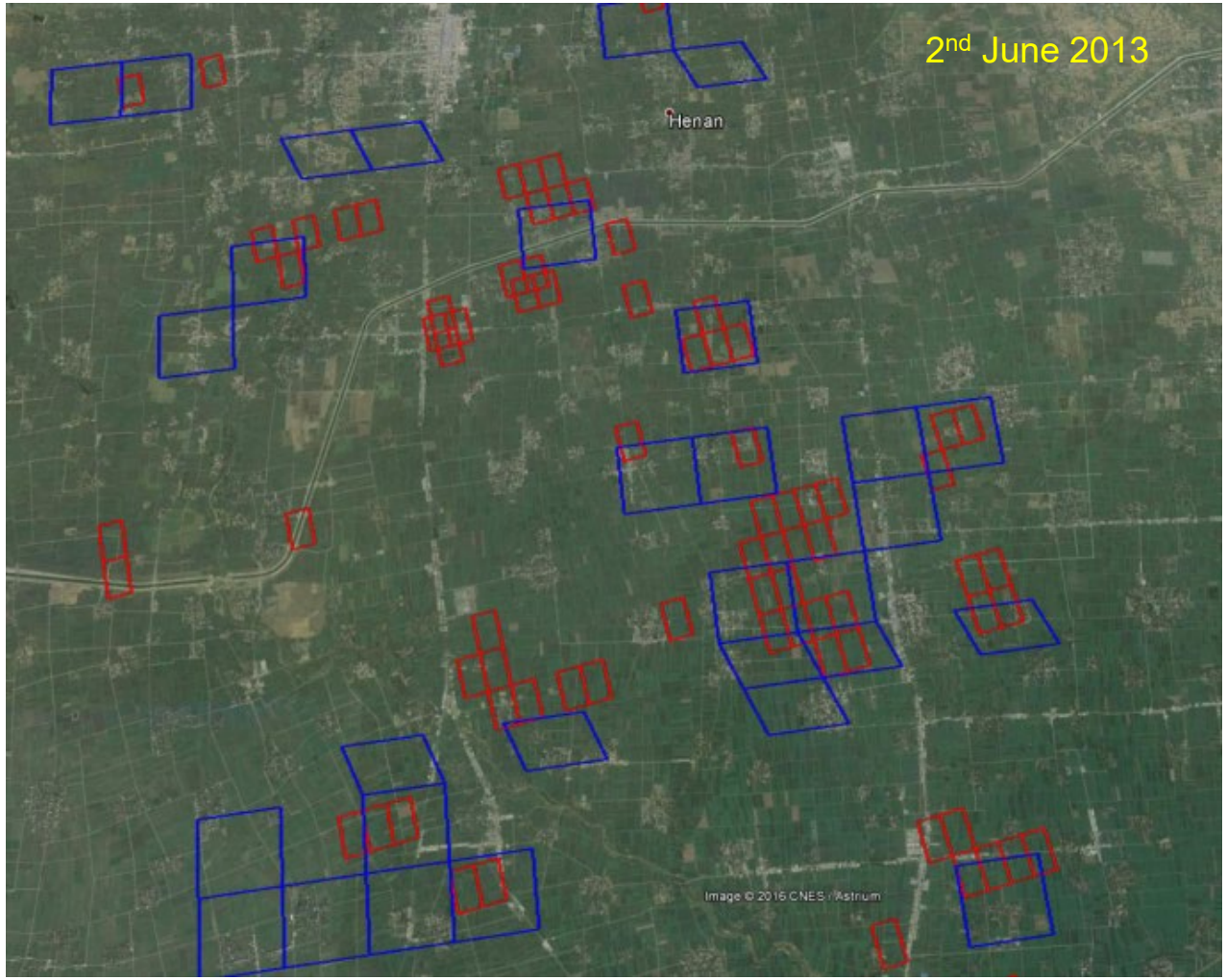
NTC SLSTR L2 FRP Product (SLSTR *vs.* Terra MODIS)





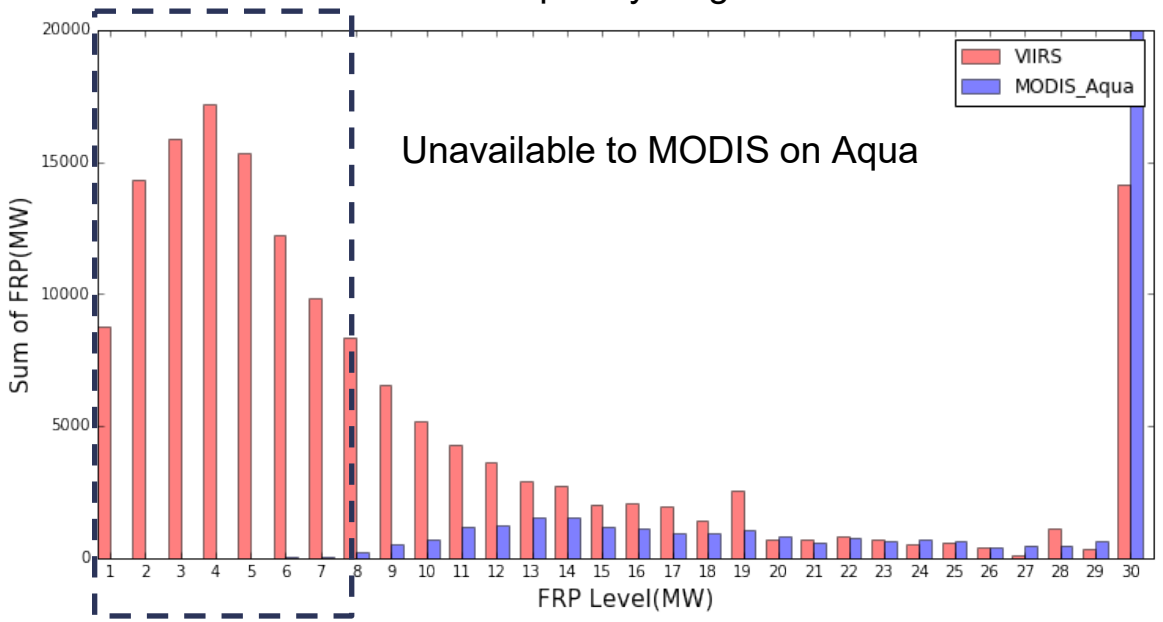
Small Pixel Benefits - Agricultural Residue Burning (China)

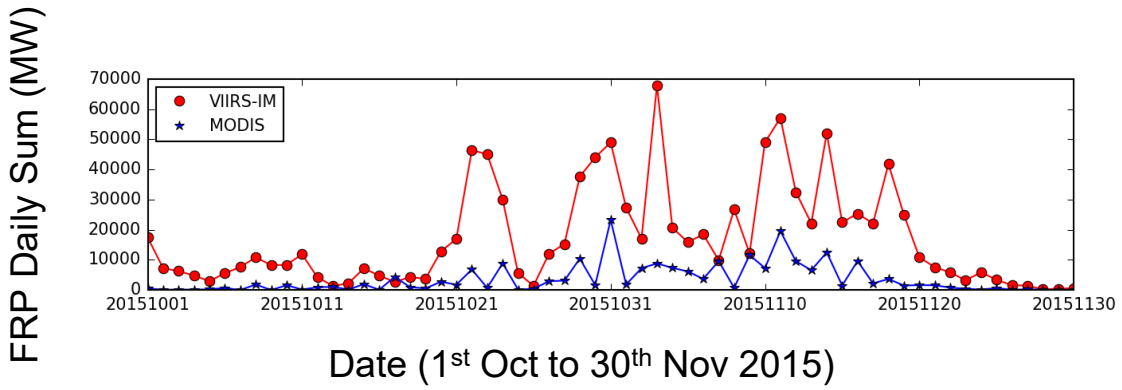
Active Fire Detections



MODIS (blue) and VIIRS-I band (red)

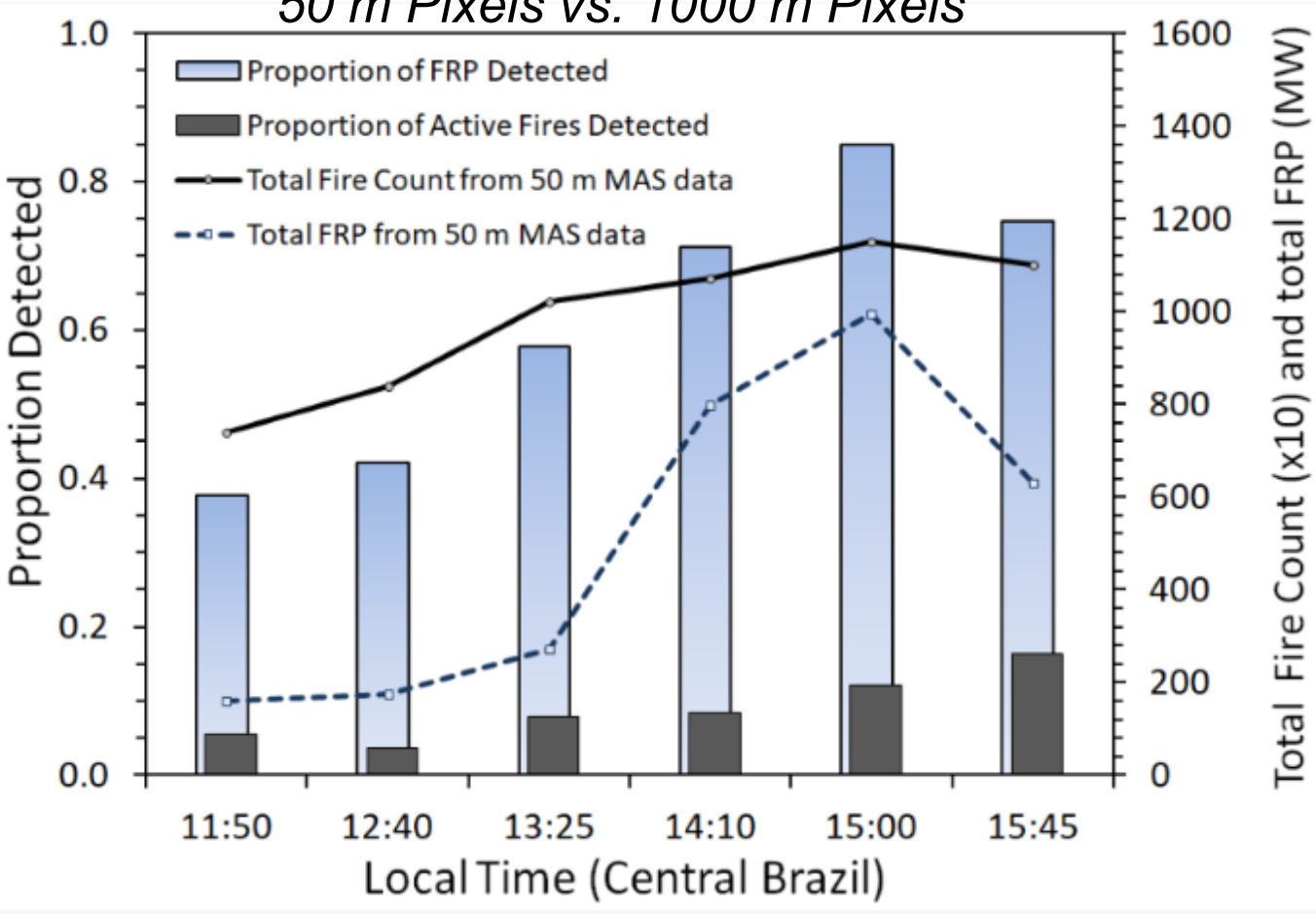
FRP Frequency Magnitude



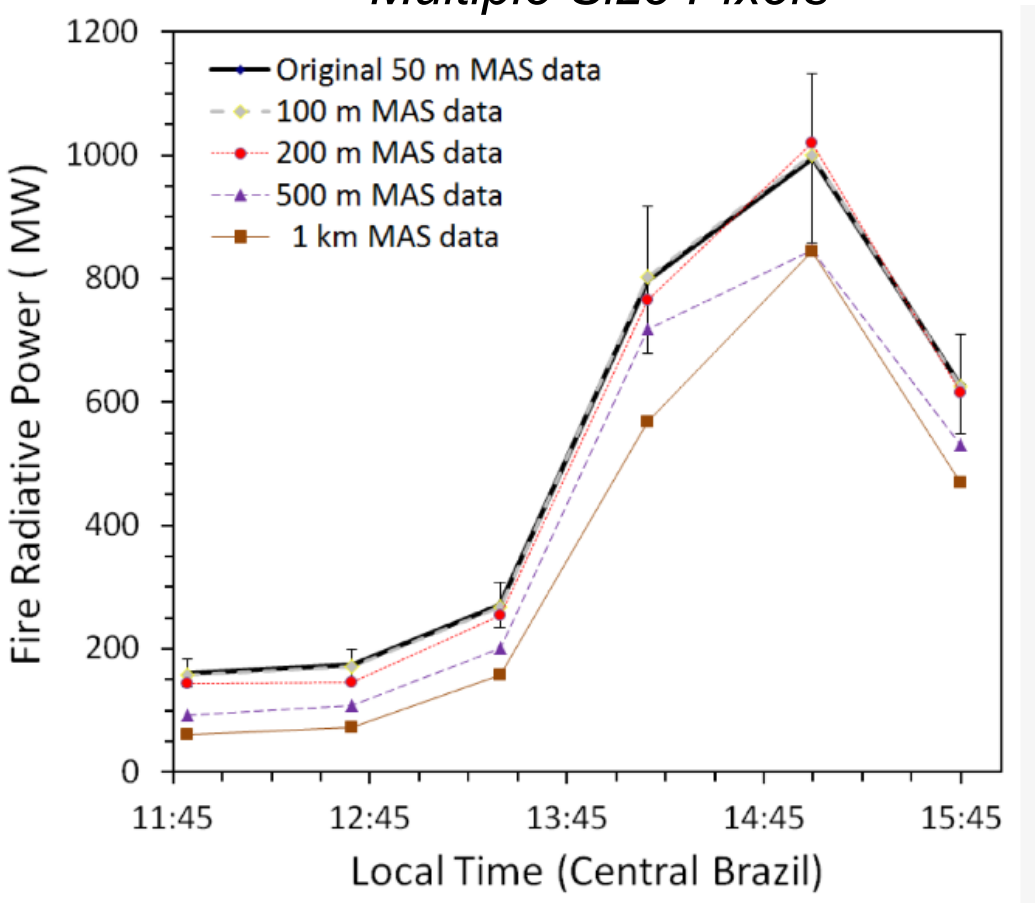


What Pixel Size Might Be Required?

50 m Pixels vs. 1000 m Pixels

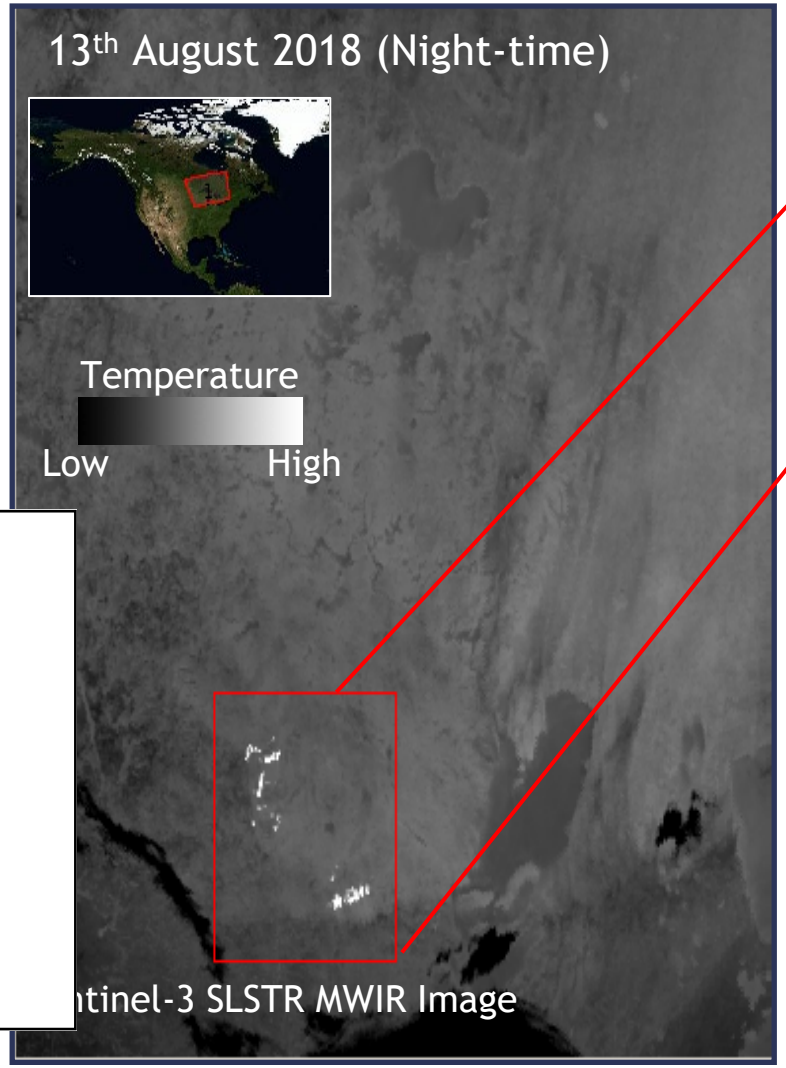


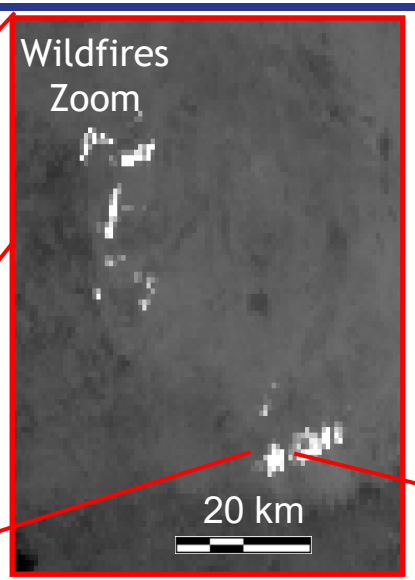
Multiple Size Pixels

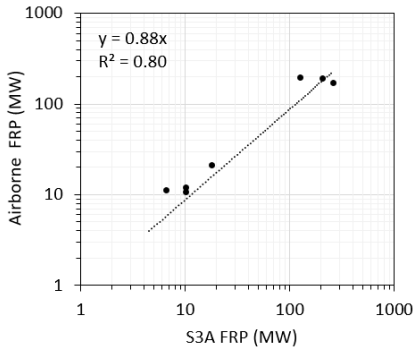


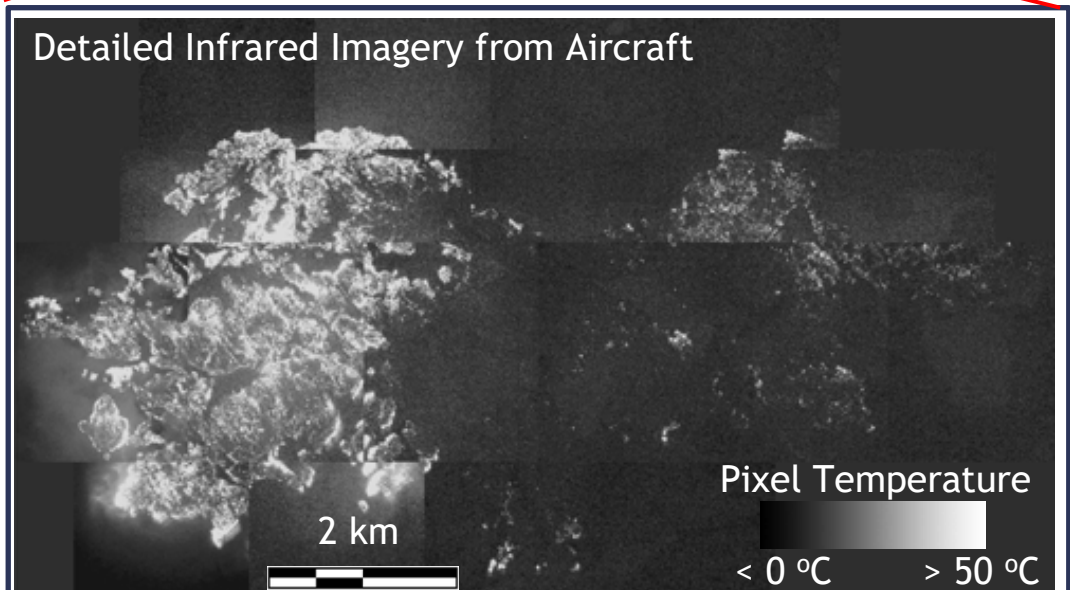
Sperling, Wooster and Malamud
https://doi.org/10.3390/fire3020011

Validation: Example of Sentinel-3 SLSTR FRP



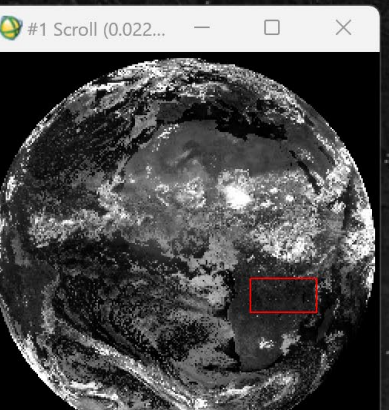






Challenge 2 – Spatial vs. Temporal Resolution Trade-off [so Rapidity of Detection vs Minimum Detectable FRP)

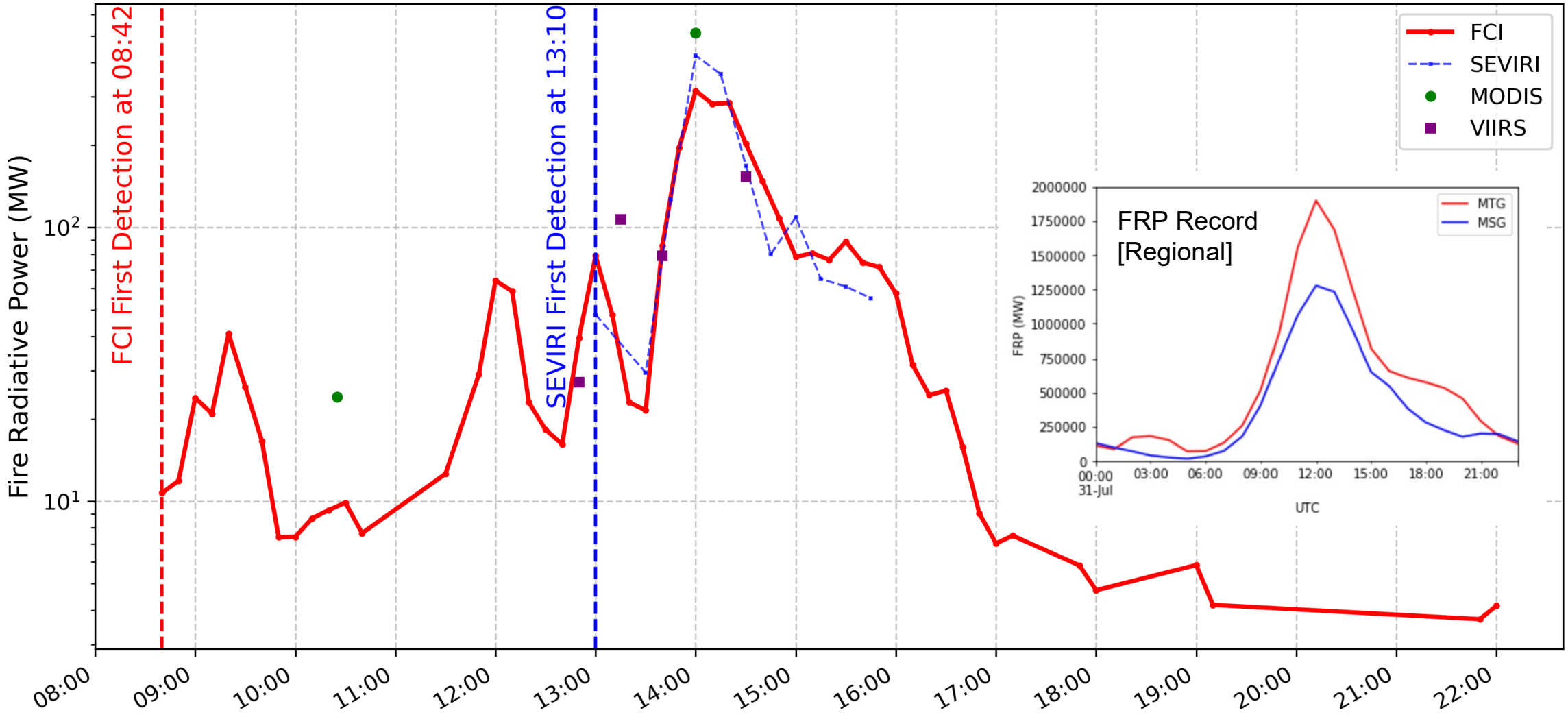
MTG FCI MWIR-LWIR Brightness Temp. Difference (1 km Data)



Southern Africa
13:00 UTC; 31 July 2024


FCI True Color 0.5km
Fire Temperature 0.5km
(3.8 and 2.2µm)
05.08.2023 10:00 UTC
Demonstrating FCI's capabilities
Observing fires in Portugal
Preliminary results

Mitigation: Rapidity of Detection & Relatively Small Pixel Area

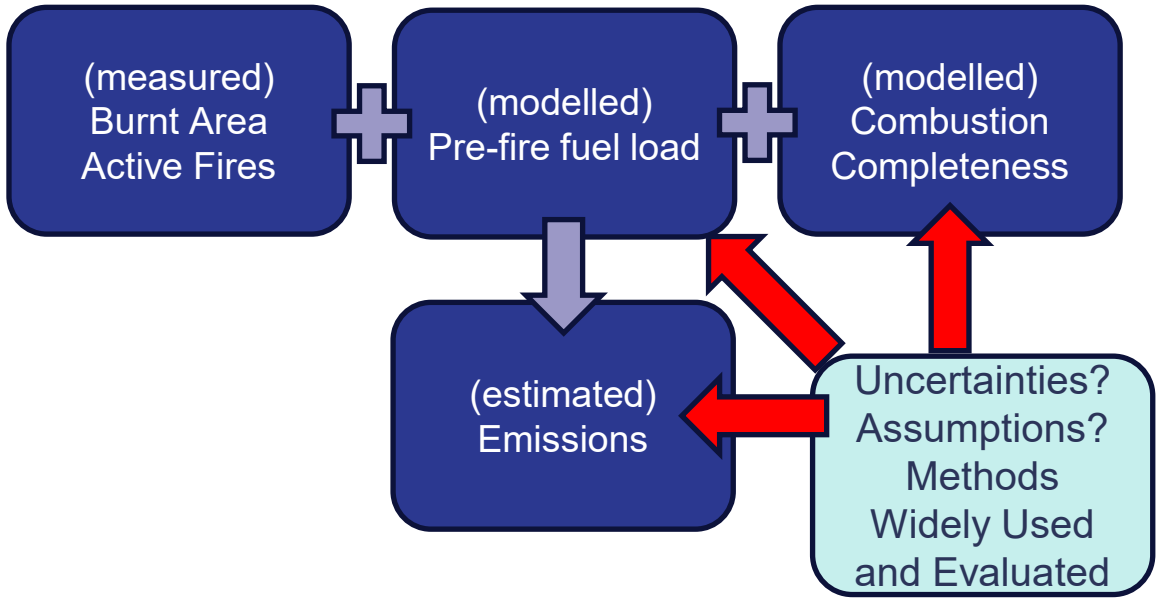


Challenge 3: Estimating Fire Emissions from AF Data

Different ways of estimating fire activity and associated emissions of gases and aerosols using Earth Observation.

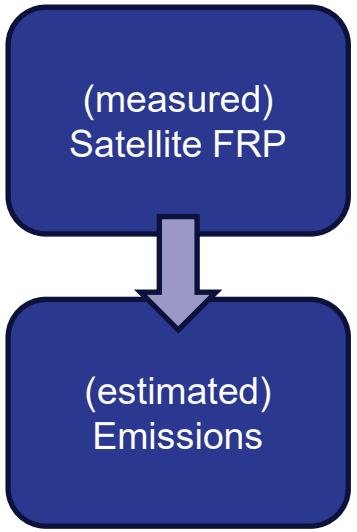
- Only way to effectively get information at regional / national / global scales consistently, and at temporal resolutions needed

"Bottom-Up"



GFED, GFAS, FLAMBE, FINN

"Top-Down"



More Quantified Uncertainties

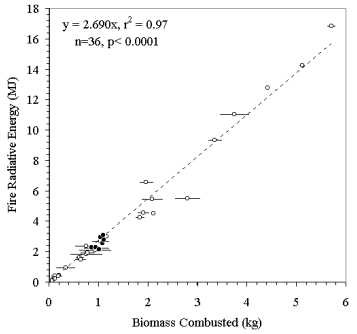
Newer and Less Tested but Based ONLY on Observations so Far Fewer Assumptions

FEER, FREM

Solution: Three Approaches to Convert FRP into Fire Emissions

Also need to use appropriate emissions factor

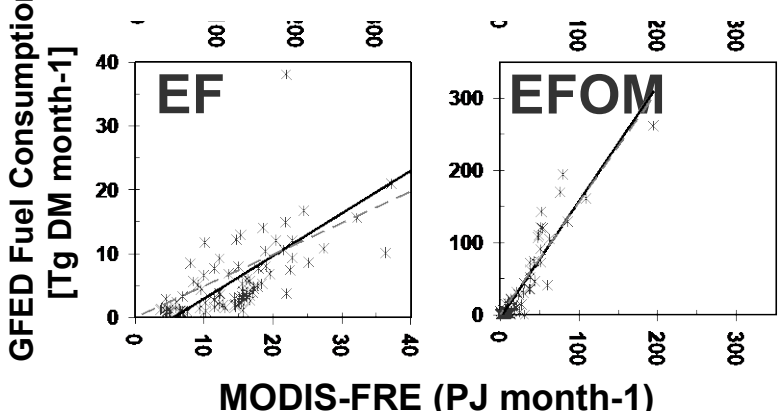
- Assume fixed conversion factor between FRP and fuel consumption rate (e.g. from ground-based experiments).



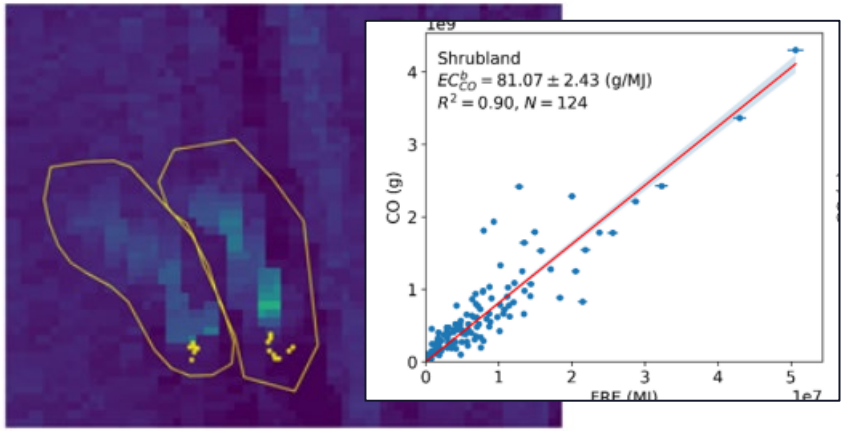
Wooster et al. (2005)

- Derive the relationship from matching FRE and fuel consumption data (e.g. GFAS uses GFED-estimated dry matter consumption).

GFAS: Kaiser et al. (2012)



- "TOP DOWN" - Derive relationship from matching FRP and smoke plume data e.g. total CO (FREM/FEER).



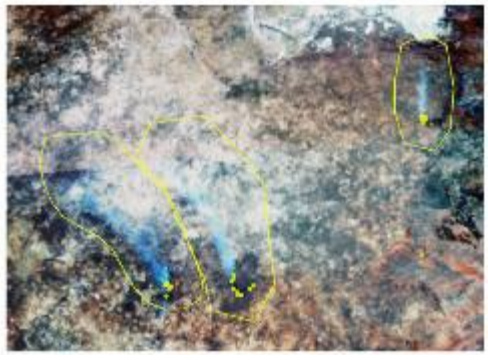
Nguyen et al. (2023)

Geostationary FRP & Sentinel-5P Total Column CO Use in FREM

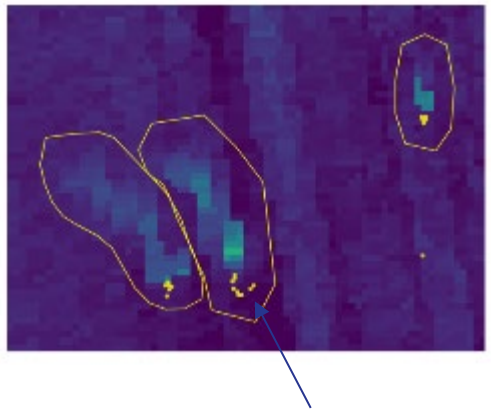
CO emissions derived from coefficients linking geostationary FRE to in-plume CO in different biomes.

Example for Three Fires

VIIRS RGB Image of Plumes

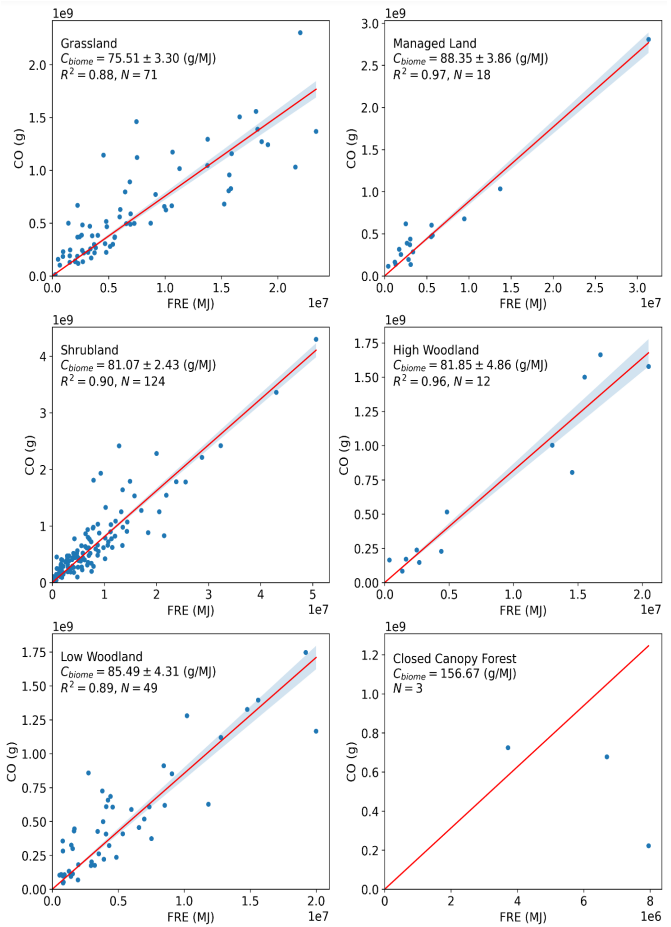


Sentinel-5P Total Column CO

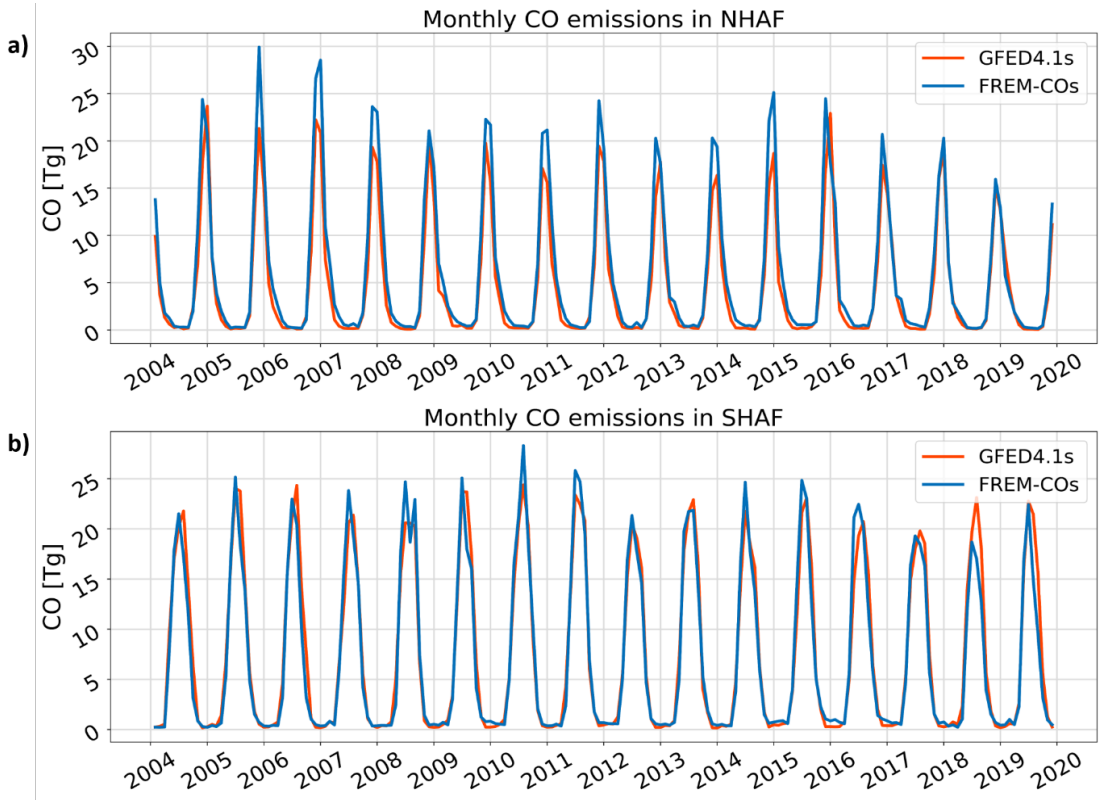


Meteosat AF Pixels where FRE is Derived

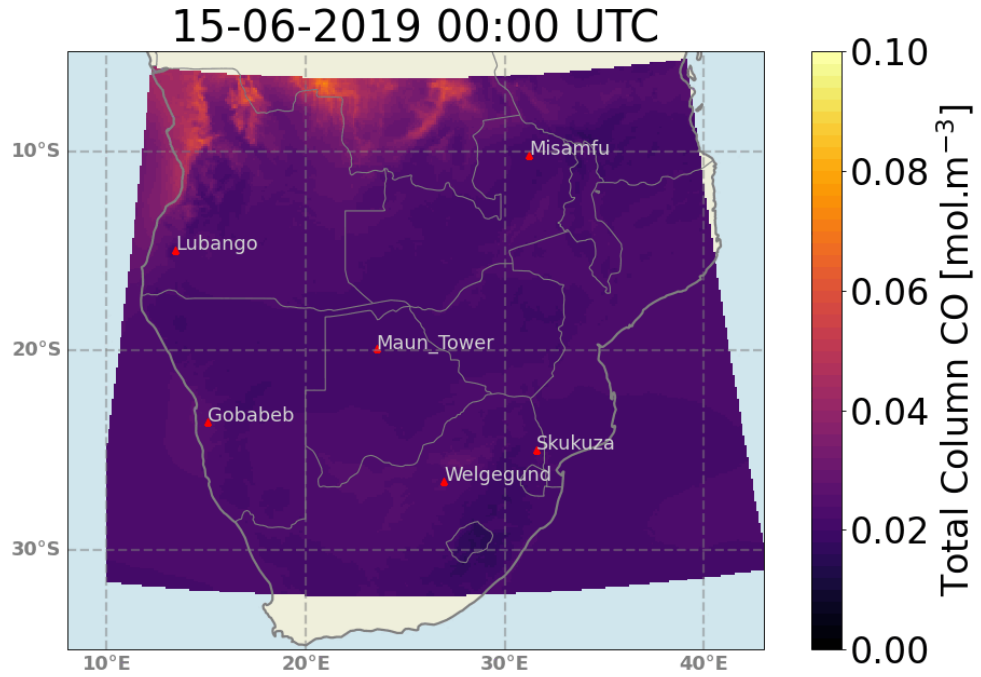
Emission Coeffs for Six "Fire Biomes"

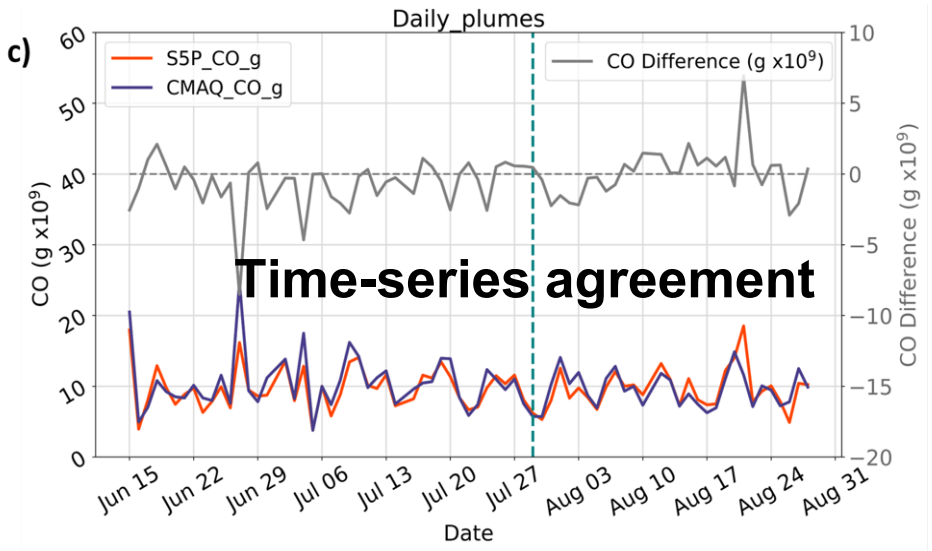


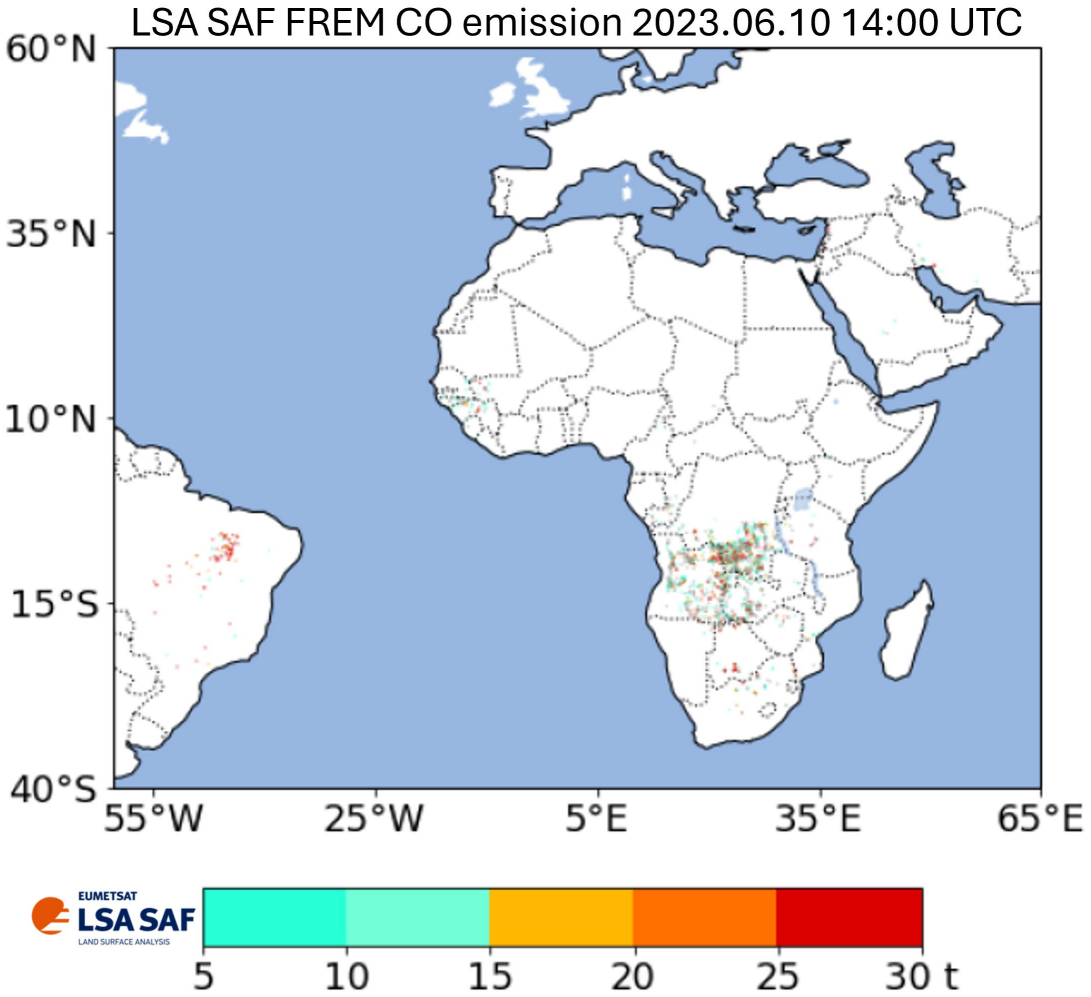
- Applied to Meteosat FRP record for Africa
- CO emission estimates very close to GFED4.1s - derived using completely different data & method

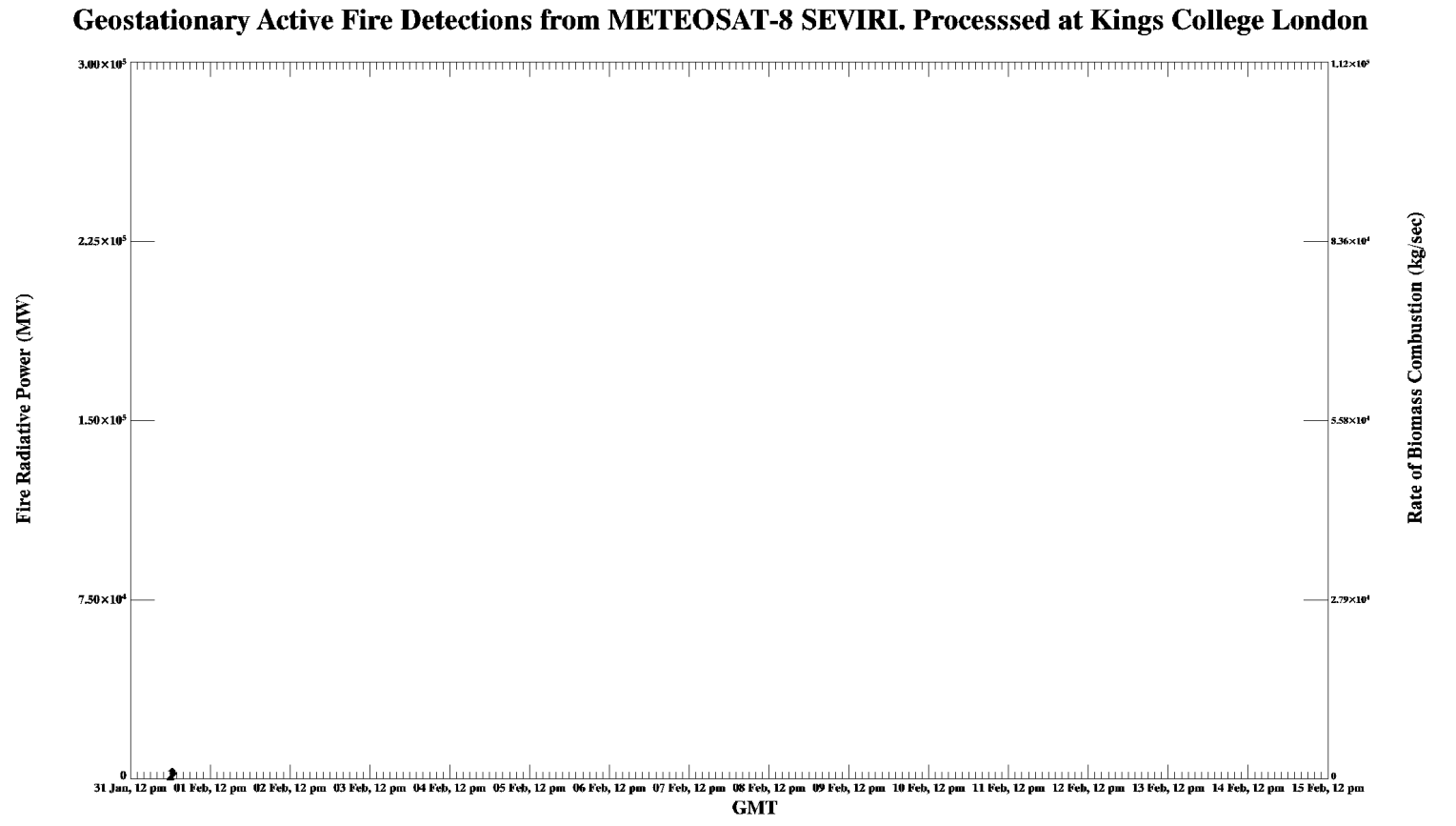


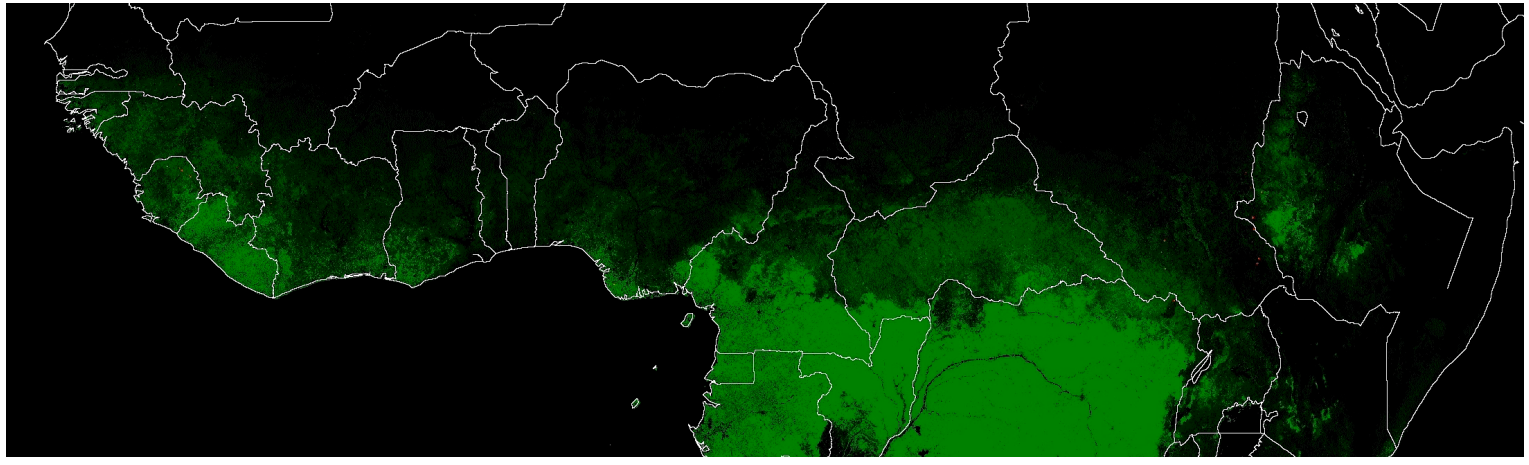
First Evaluation of FREM Approach & Operational Product



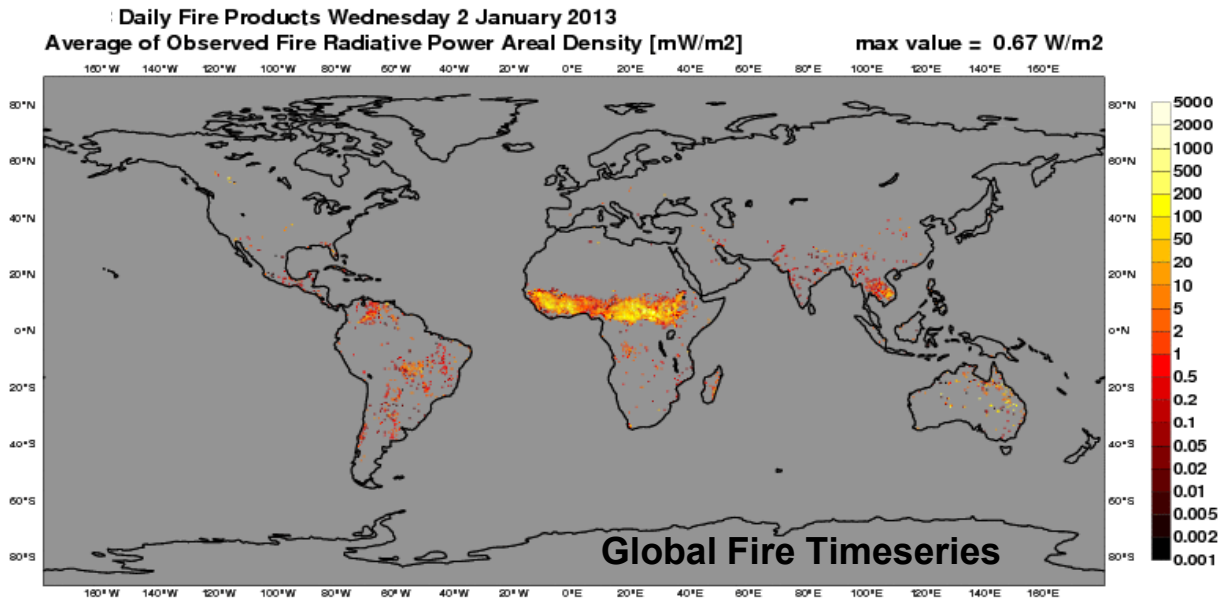


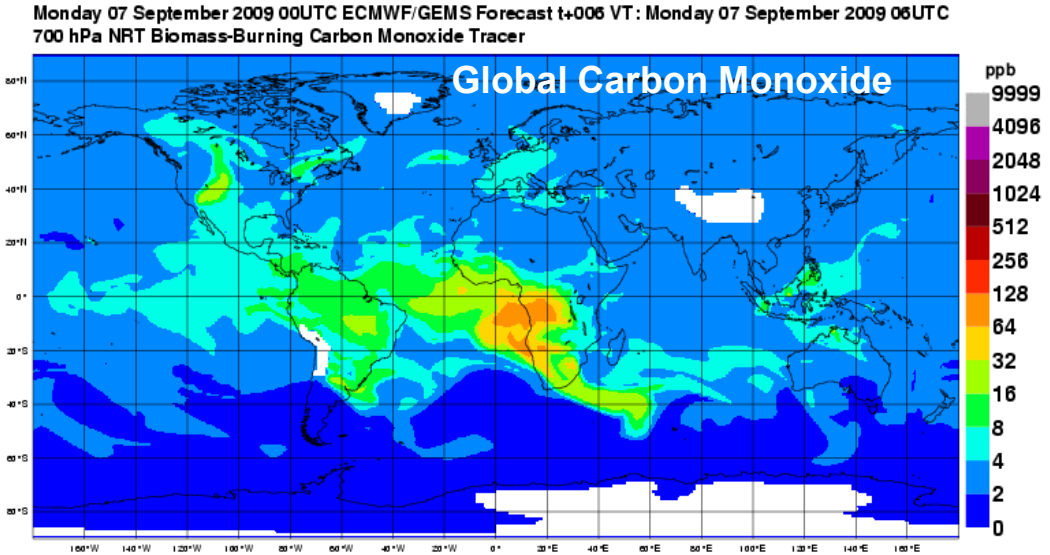


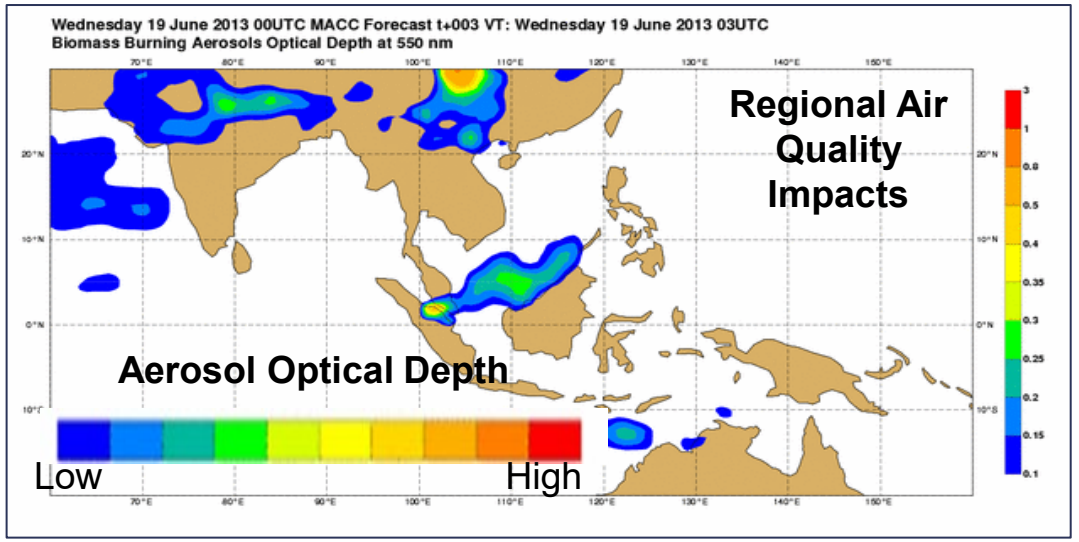

Geostationary Active Fire Detections from METEOSAT-8 SEVIRI. Processsed at Kings College London
Fire Radiative Power (MW)
3.00×10⁵
2.25×10⁵
1.50×10⁵
7.50×10⁴
0
Rate of Biomass Combustion (kg/sec)
1.12×10⁵
8.36×10⁴
5.58×10⁴
2.79×10⁴
0
31 Jan, 12 pm 01 Feb, 12 pm 02 Feb, 12 pm 03 Feb, 12 pm 04 Feb, 12 pm 05 Feb, 12 pm 06 Feb, 12 pm 07 Feb, 12 pm 08 Feb, 12 pm 09 Feb, 12 pm 10 Feb, 12 pm 11 Feb, 12 pm 12 Feb, 12 pm 13 Feb, 12 pm 14 Feb, 12 pm 15 Feb, 12 pm
GMT

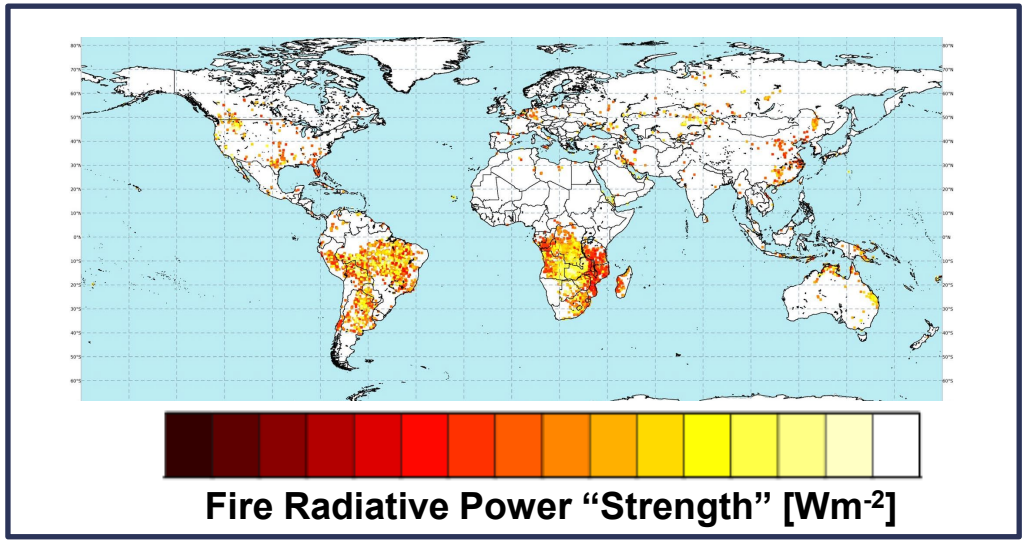


Global, Real-Time Fire Information

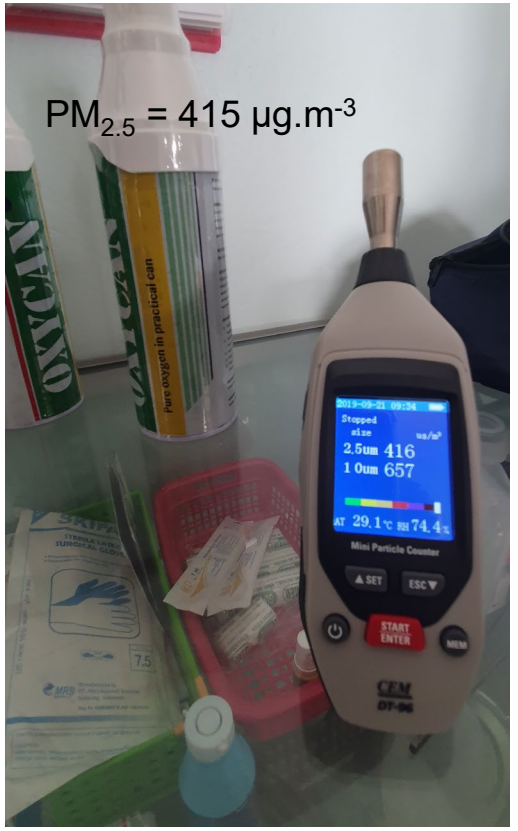


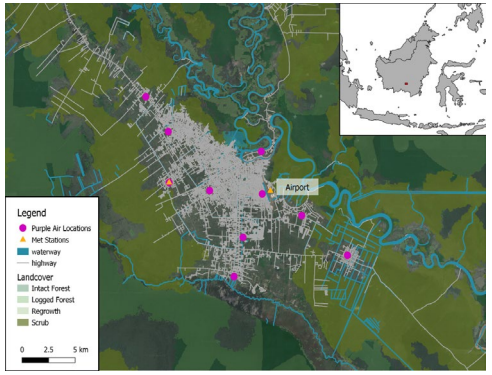






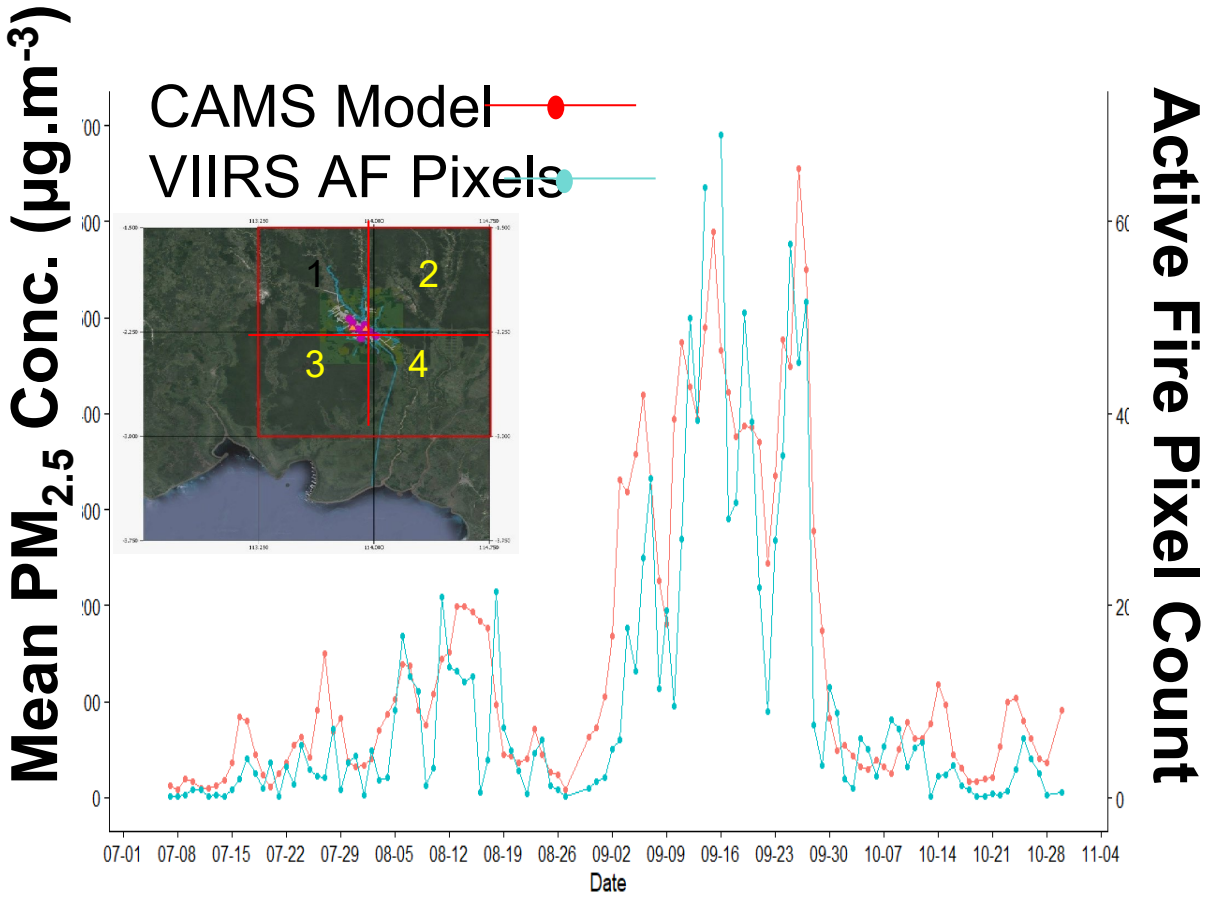
El Niño & Fire, Air Quality & Health in SE Asia



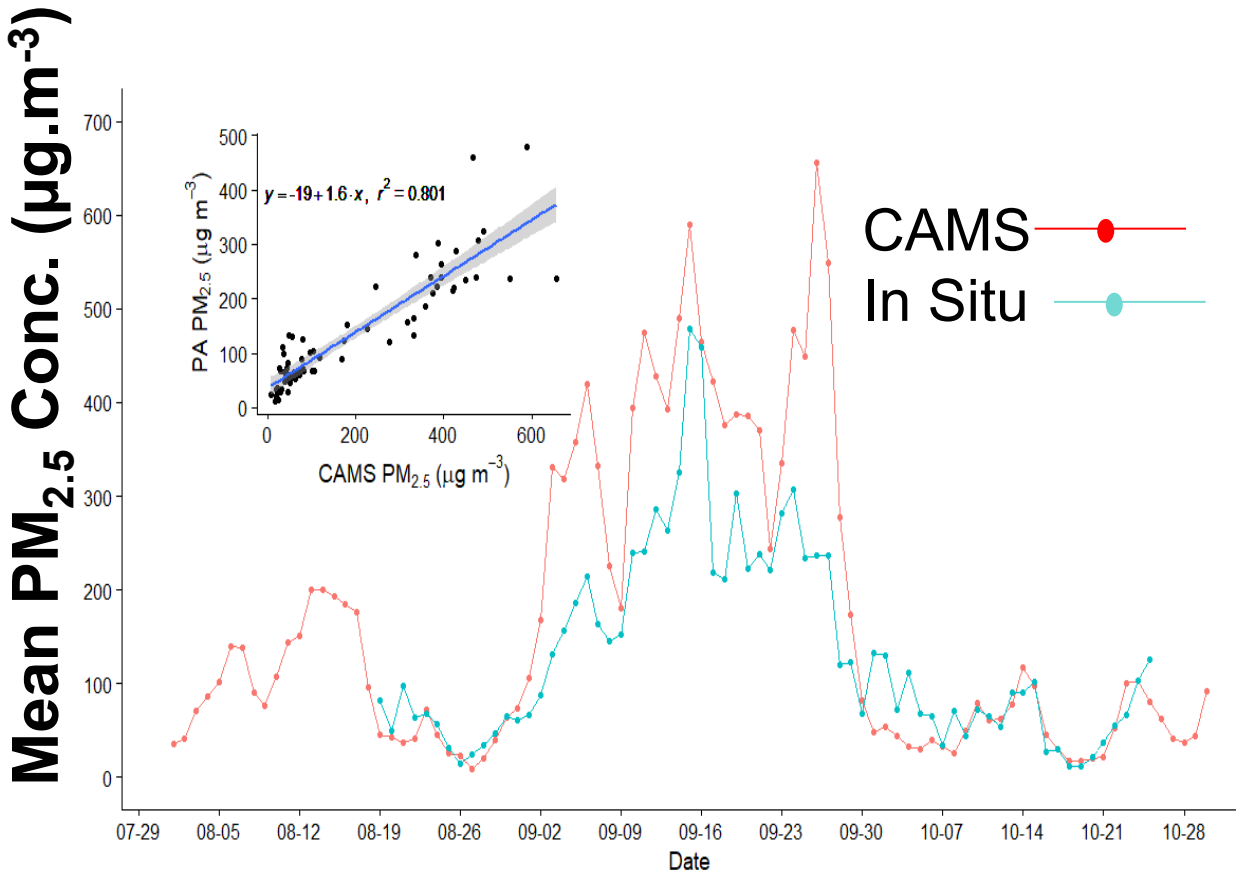


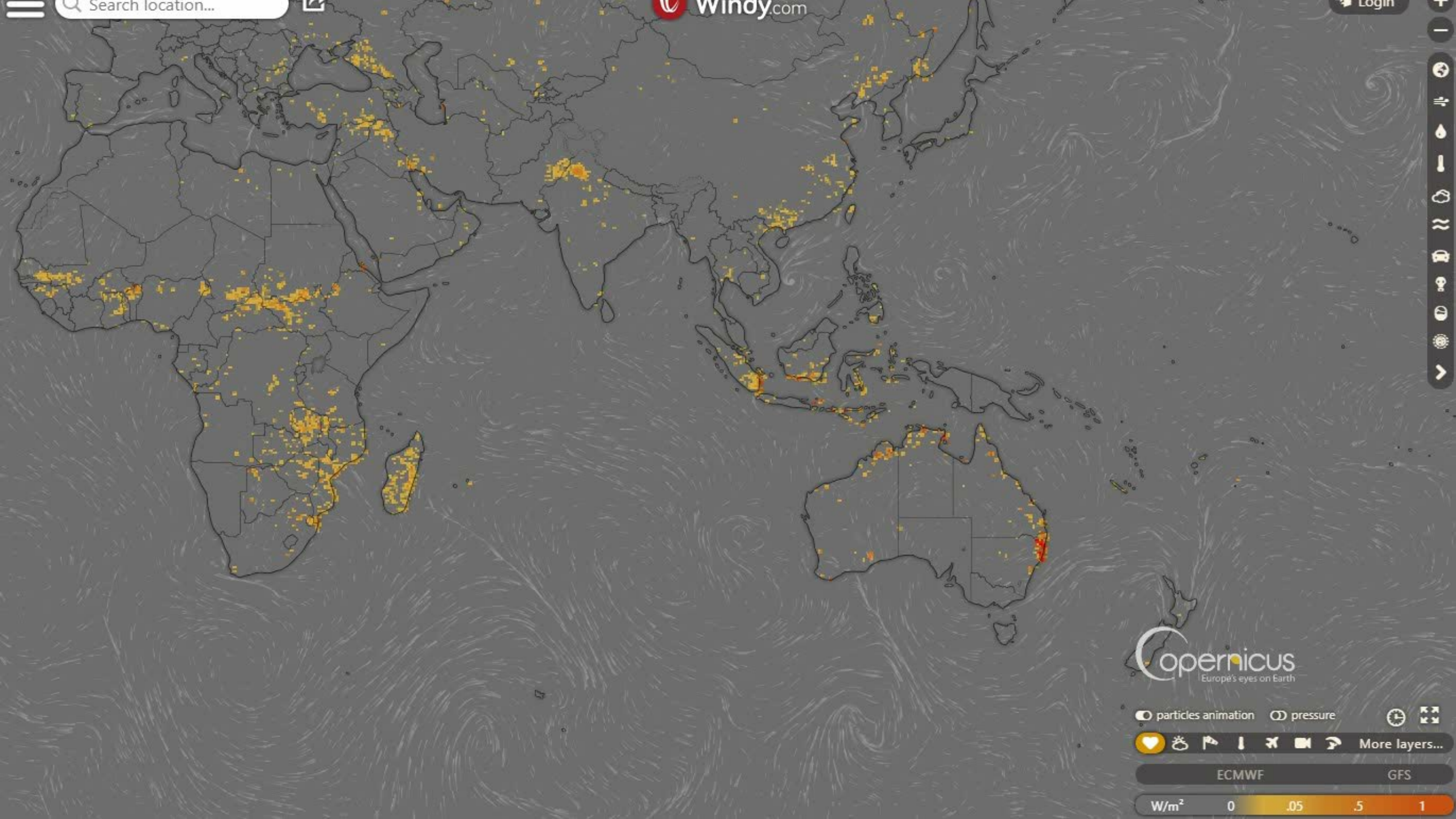
Evaluation of CAMS Model $PM_{2.5}$ Surface Conc.

$PM_{2.5}$ & AF Pixel Counts



CAMS model $PM_{2.5}$ vs. *In Situ* $PM_{2.5}$

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