Fire Radiative Power Emissions Perspective

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National Academies Greenhouse Gas Emissions from Wildland Fires
Workshop
September 13–15, 2023

Requested Discussion Topics (Paraphrased)

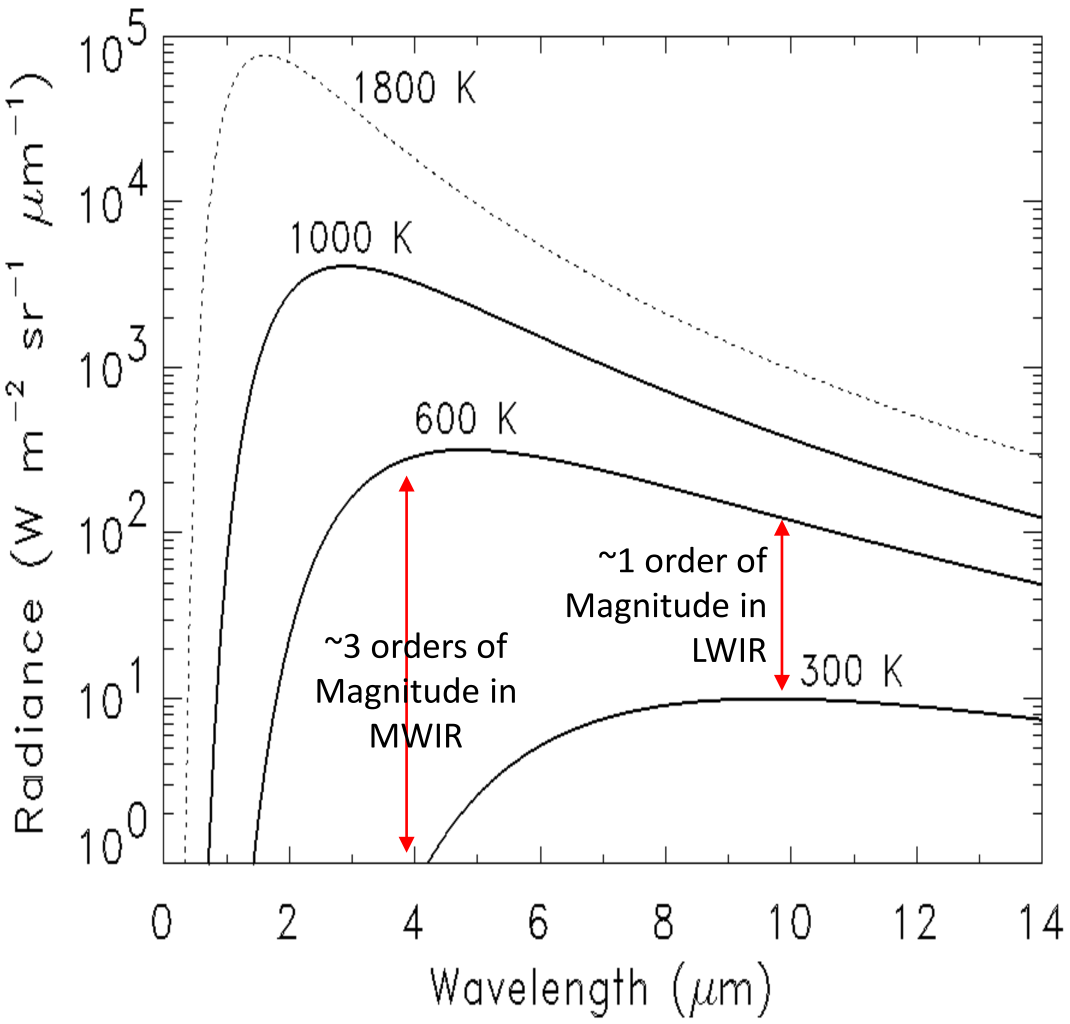
- Description of approach used to quantify fire emissions using FRP (theory and inventory available), and differences at landscape to global domains?

- Largest gaps, uncertainties, constraints, limitations, and/or challenges in defining the temporal, spatial, & vertical domain using the FRP-based approach.

- What single measure would you support to bring us closer to estimating the reality of what is burned on the ground, under the variety of fuel and fire weather conditions?

Description of FRP Approach to Fire Emissions

Based on Active Fire Pixel Detection



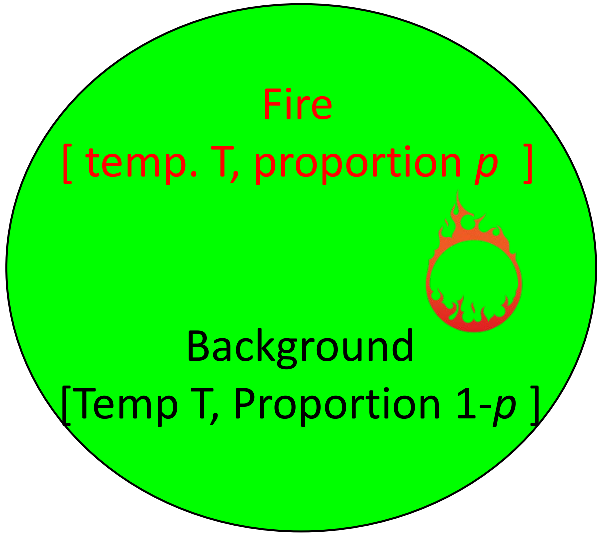
Key advantages

- Probably most direct method that requires least assumptions
- Can deliver fire emissions estimates in close to real-time

Planck's Radiation Law

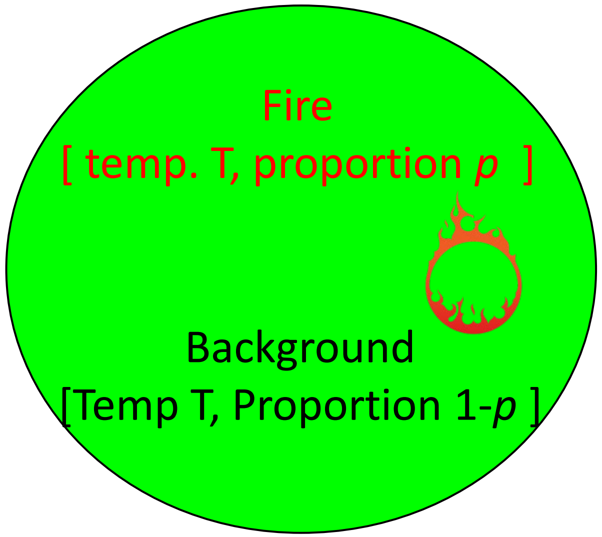
$$L(\lambda,T) = \frac{C_1}{\lambda^5(\exp(\frac{C_2}{\lambda T})-1)}$$

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

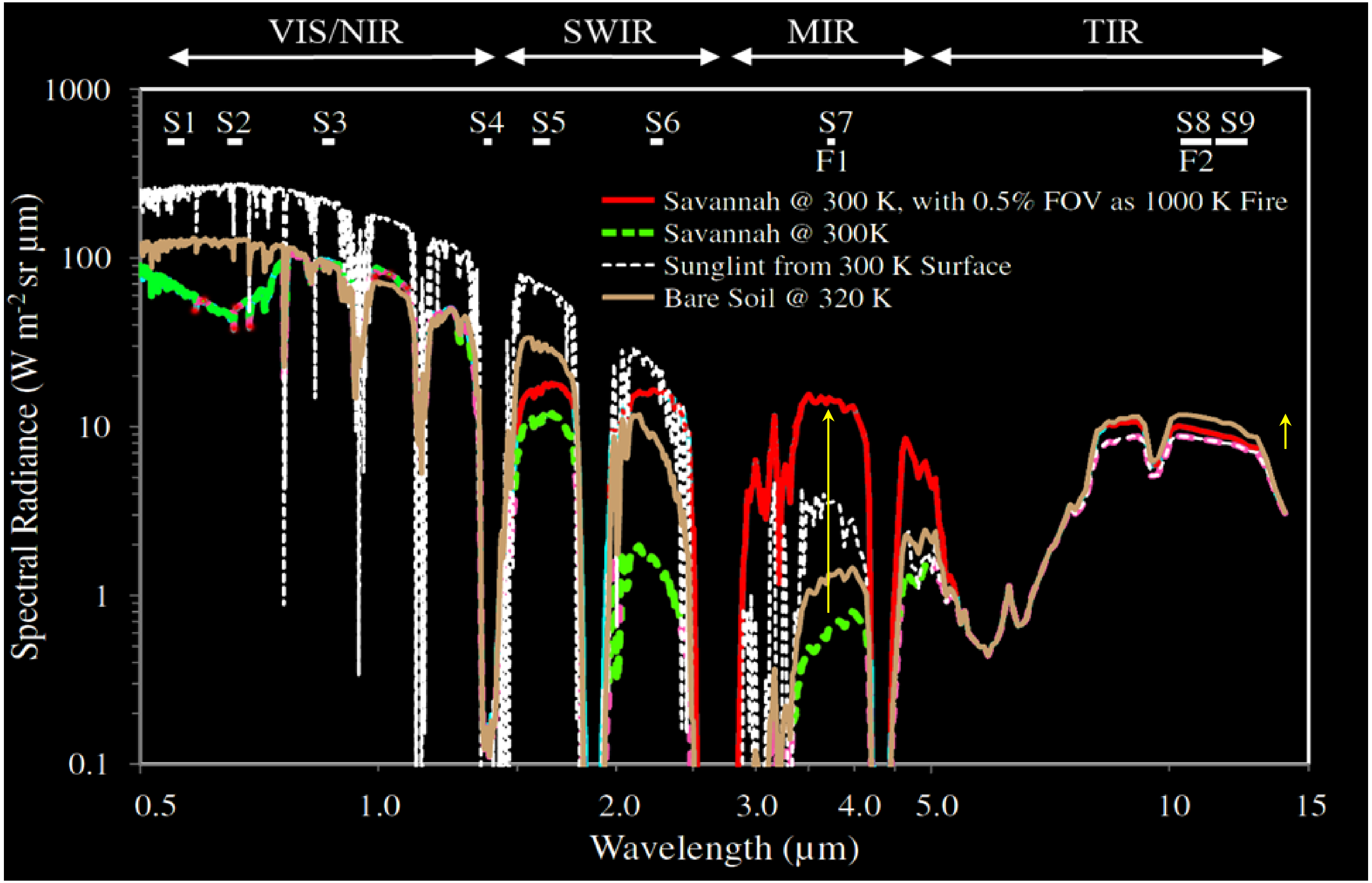


Ground Pixel Coverage
e.g. 1 km MODIS Thermal IR Pixel

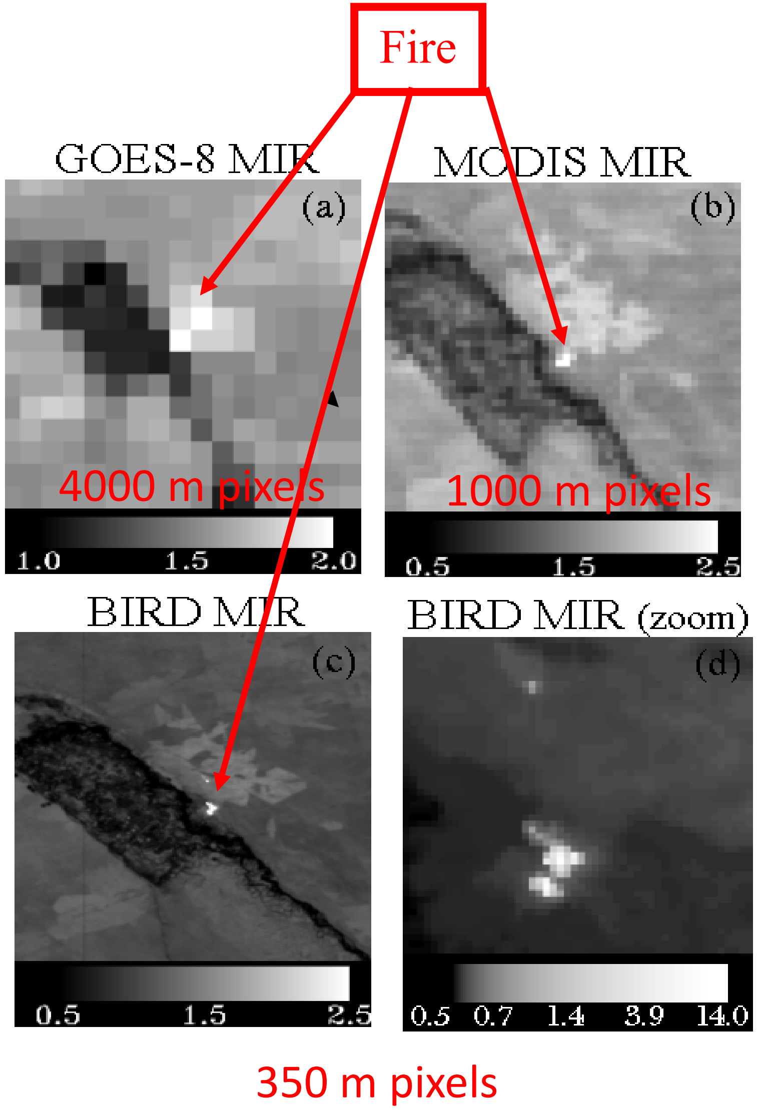
Radiative Transfer of Active Fire Detection

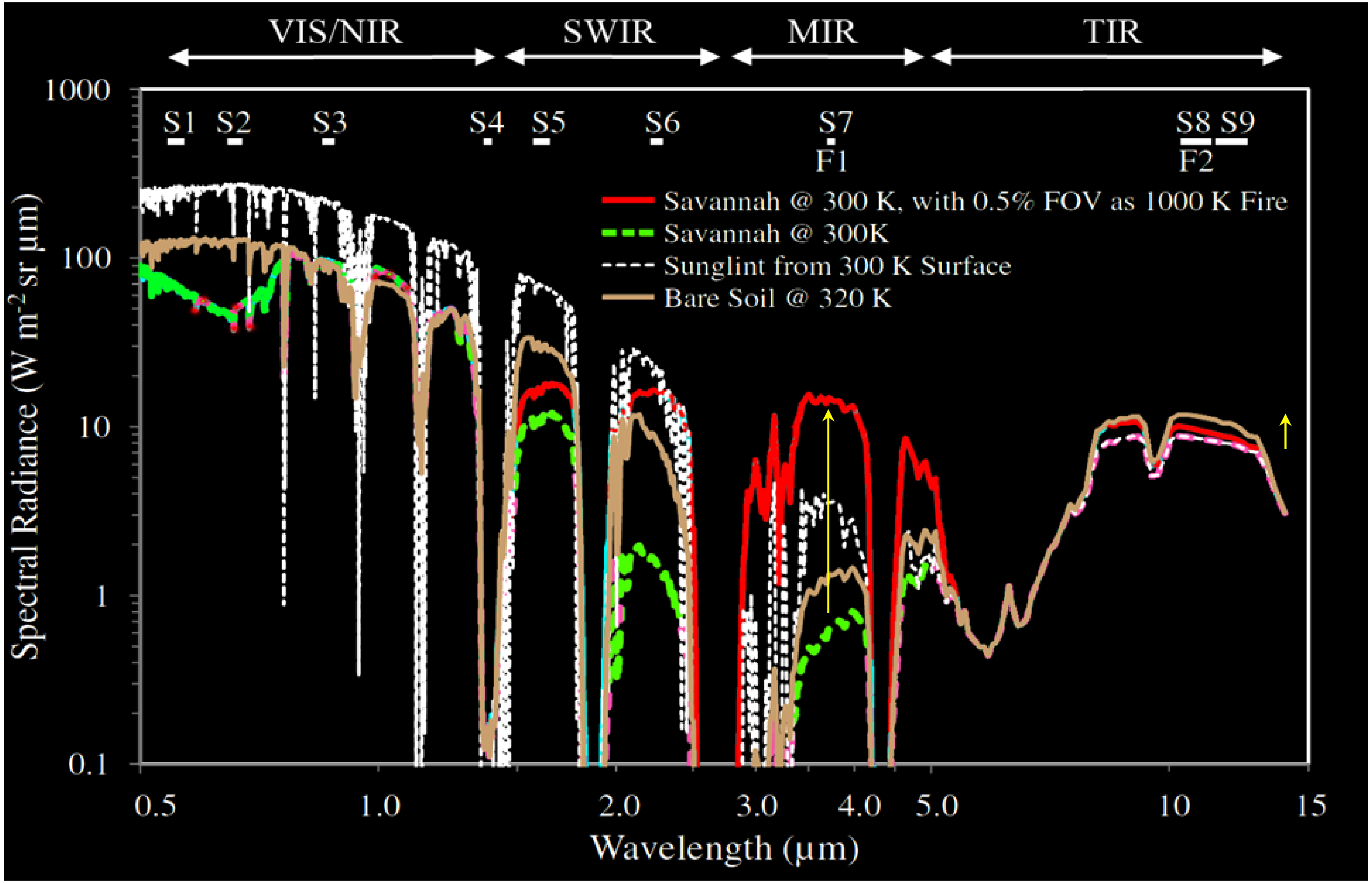


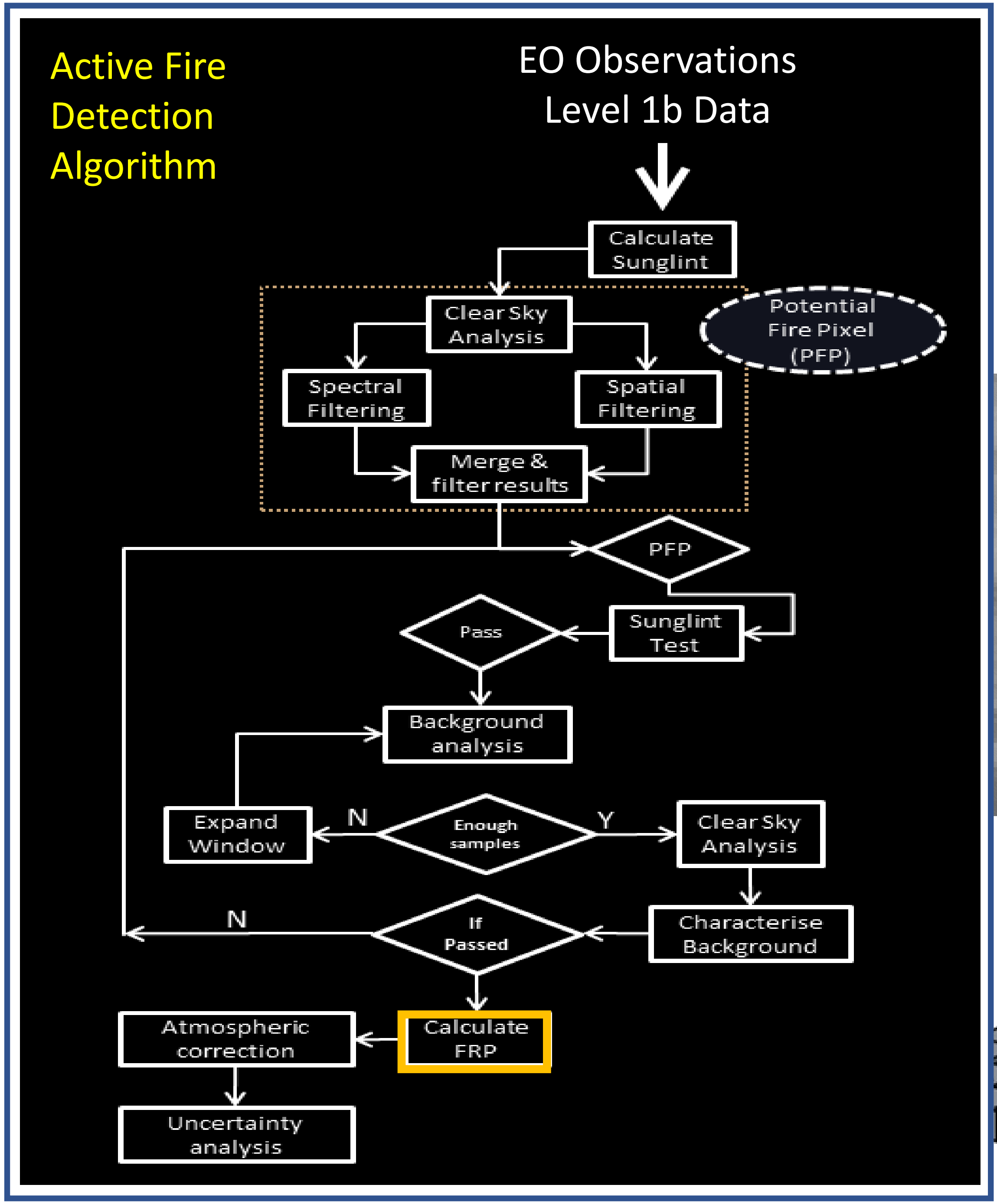
P = 0.01 (1%)



Radiative Transfer of Active Fire Detection

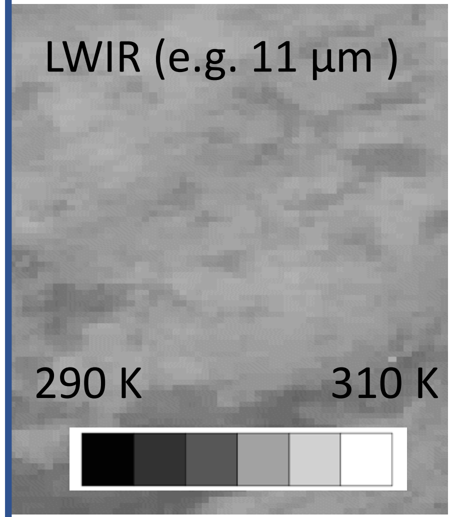


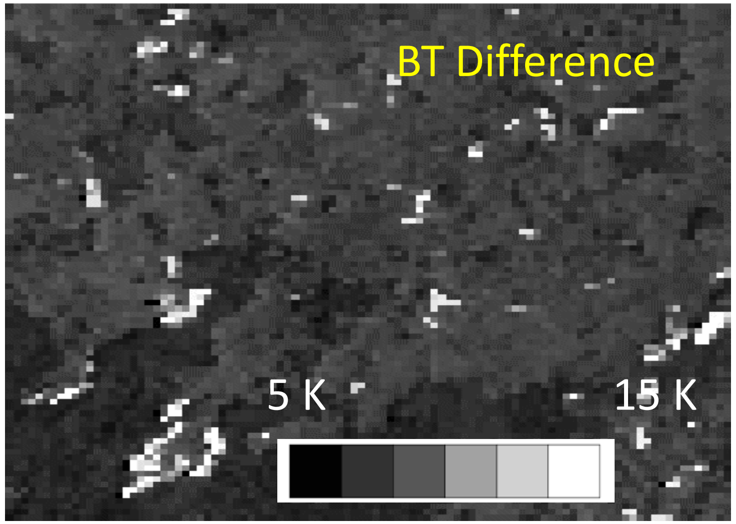


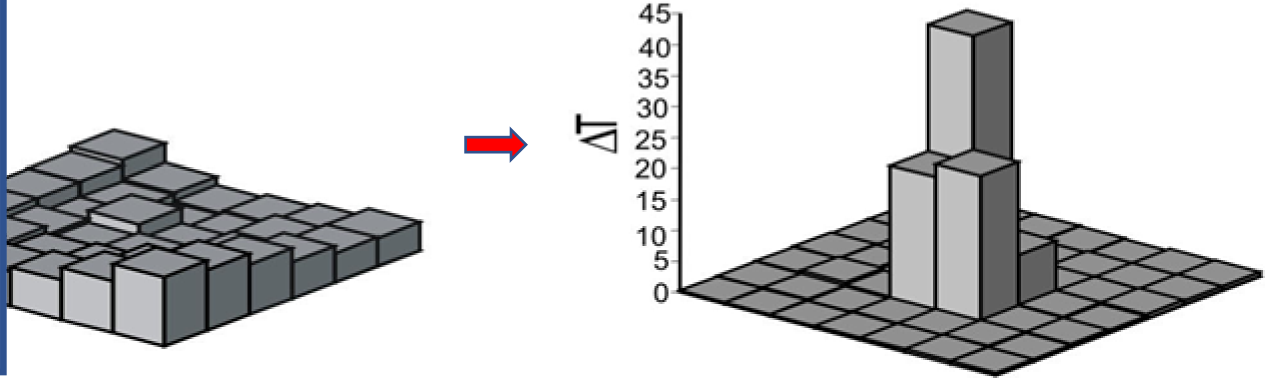


$$T = \frac{c_2}{\lambda \ln\left[\left(\frac{C_1}{\pi L_\lambda \lambda^5}\right) + 1\right]}$$

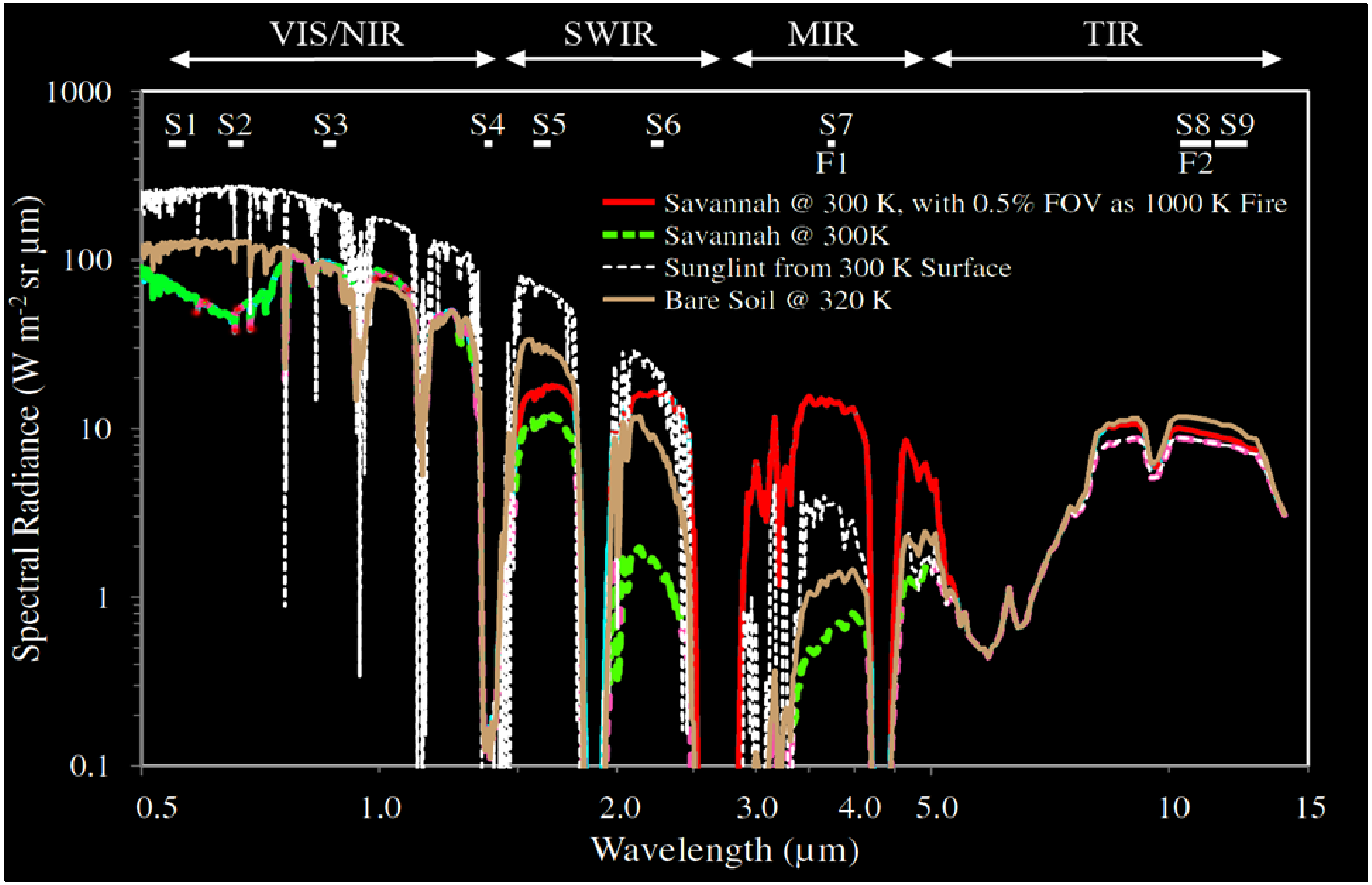
Brightness Temperature
[Kelvin]

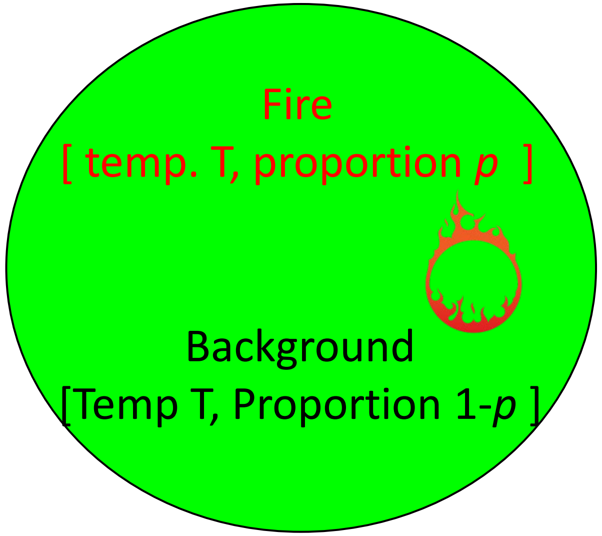






Fire Radiative Power [FRP] of Active Fire Pixel



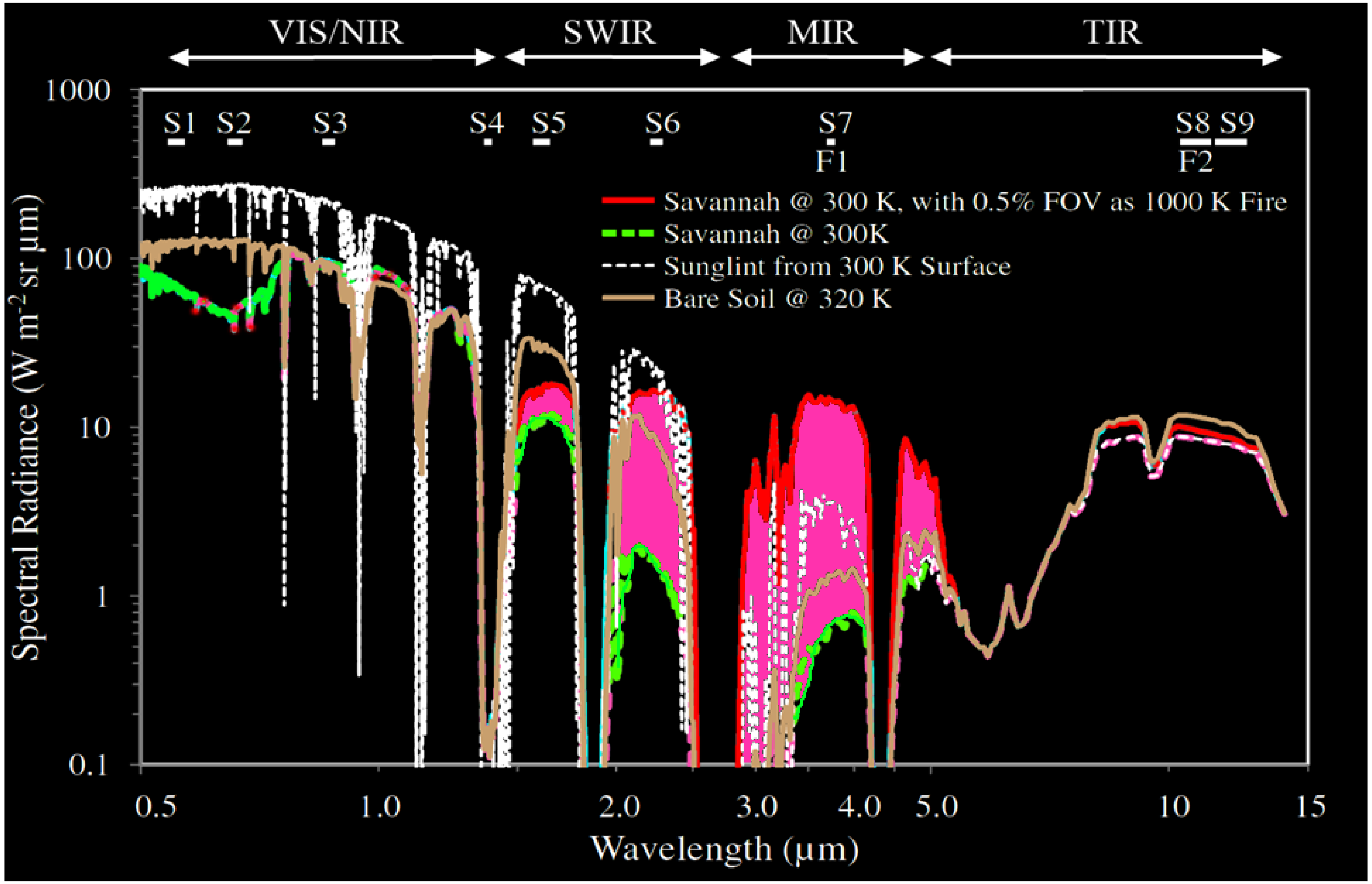


P = 0.01 (1%)

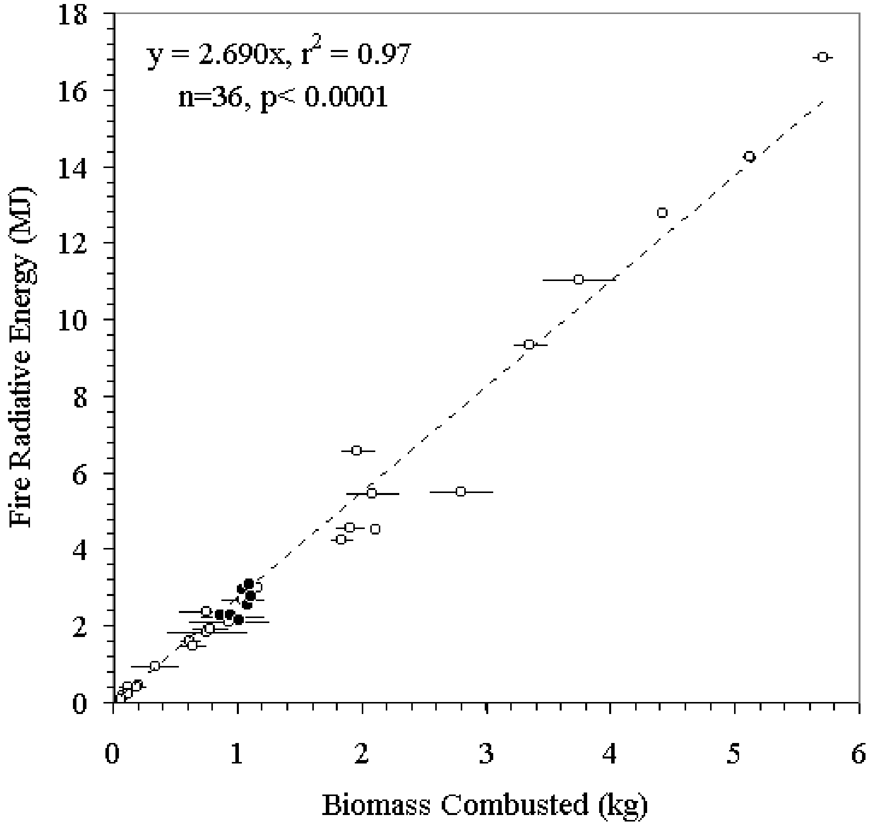
Retrieve FRP estimate using either:

- Single waveband (MIR radiance) approach
- Multispectral approach to estimate fire characteristics, then derive FRP from e.g. Stefan-Boltzmann Law.

Fire Radiative Power [FRP]



Relation to Fuel Consumption



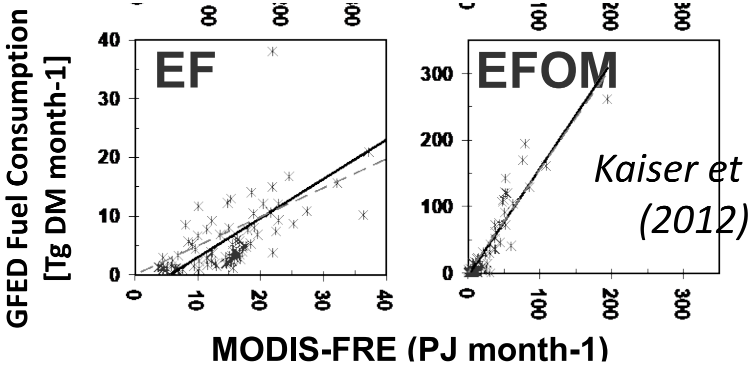
FRE = temporal integral of FRP over fire lifetime
FRE relates to fuel consumption
FRP relates to fuel consumption rate

Three ways to convert FRP data into smoke emissions

Also need to use appropriate emissions factor

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

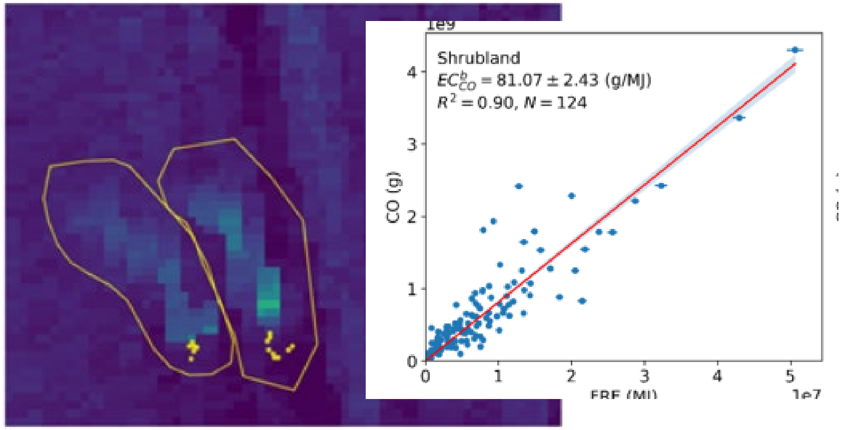
- Derive the relationship from matching FRE and fuel consumption data (e.g. GFAS uses GFED-estimated dry matter consumption)



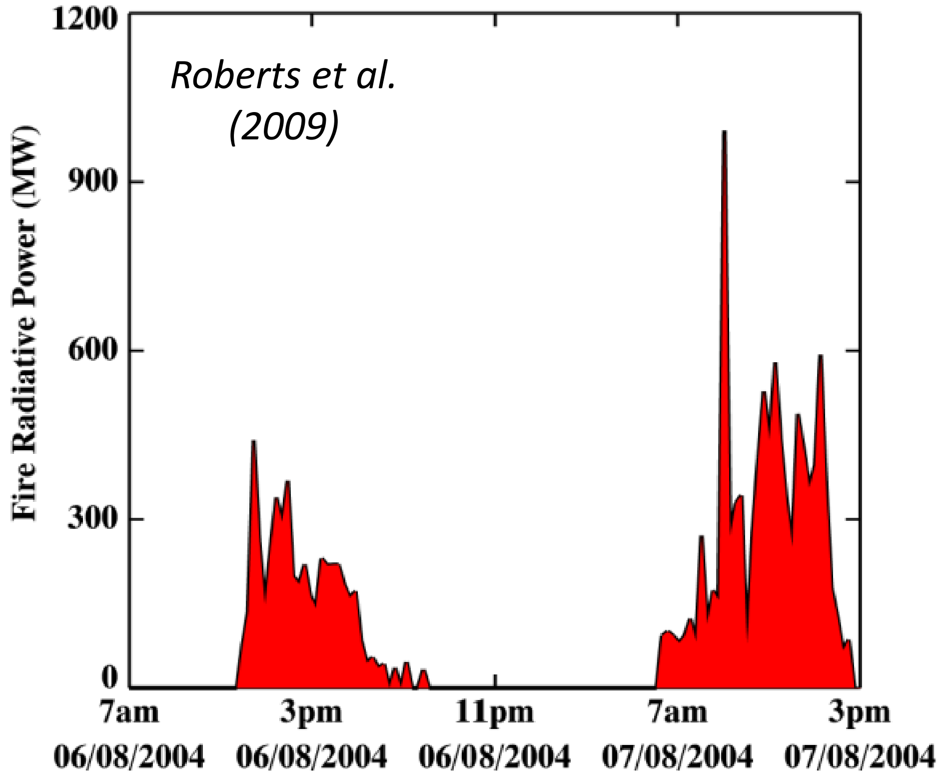
Kaiser et al. (2012)

- Derive relationship from matching FRE or FRP and smoke plume data (e.g. FREM or FEER)

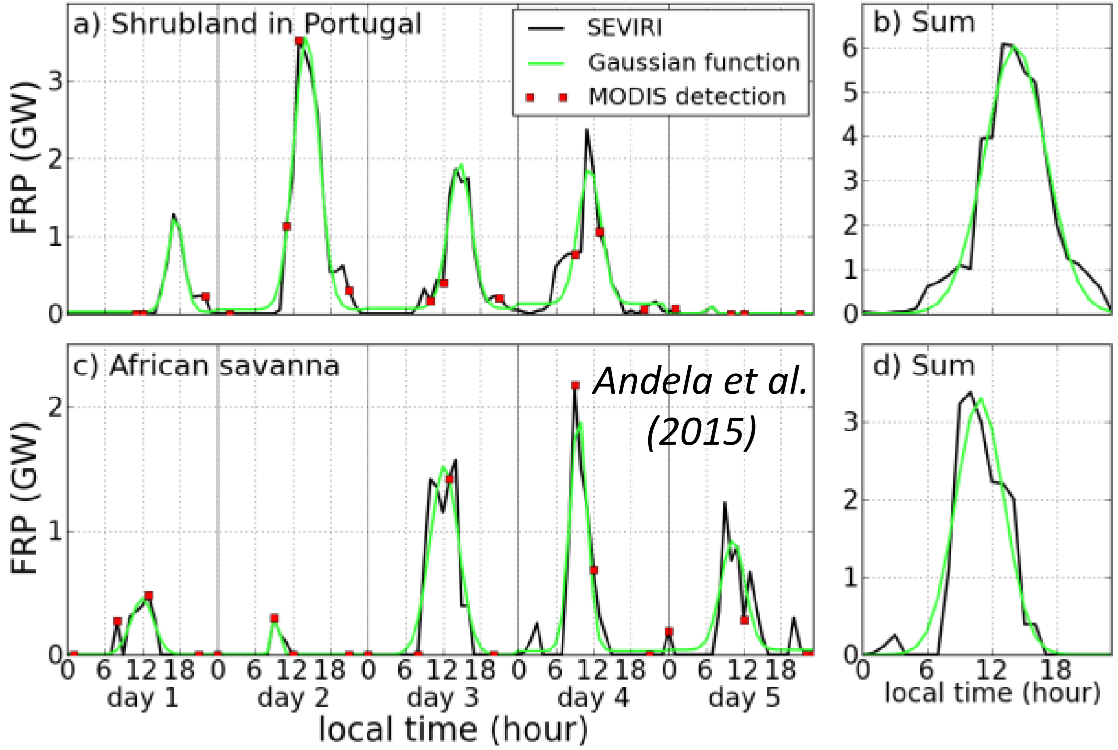
Nguyen et al. (2023)



Landscape *vs.* Global Domain Difference



Single landscape fire (Botswana) with FRP derived from Meteosat SEVIRI at 15-min intervals, used to directly generate FRE total.



FRP diurnal cycles derived from Meteosat SEVIRI data and used with MODIS data to generate FRE from FRP data at 0.1 deg grid cell scale.

Uncertainties and Challenges

- Smaller (e.g. agricultural) or cooler (e.g. tropical peat) fires can remain undetected, esp with data from coarser scale sensors (detectability scales with pixel area, which varies with view angle).

- FRP changes fast - making satellite FRP retrievals hard to validate, and retrievals require wide dynamic range MIR band. Retrievals can be quite uncertain for smallest detected fires, yet saturated at the most extreme fires. Smaller pixel areas and appropriately increased dynamic range will help.

- Atmospheric correction remains a little uncertain. MIR radiance method contains some uncertainty from algorithmic approach and may underestimate FRP from coolest fires (e.g. peat burns), whilst multispectral methods may tend to introduce noise into retrievals.

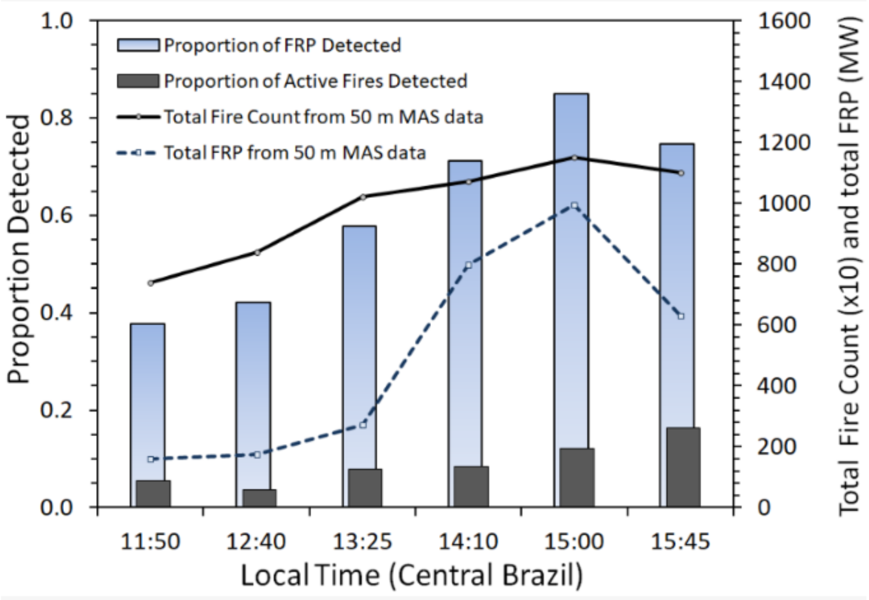
- Going from FRP to FRE is subject to uncertainty due to e.g. cloud cover, AF pixel non-detection, and imperfect fire diurnal cycle assumption when using polar orbiters.

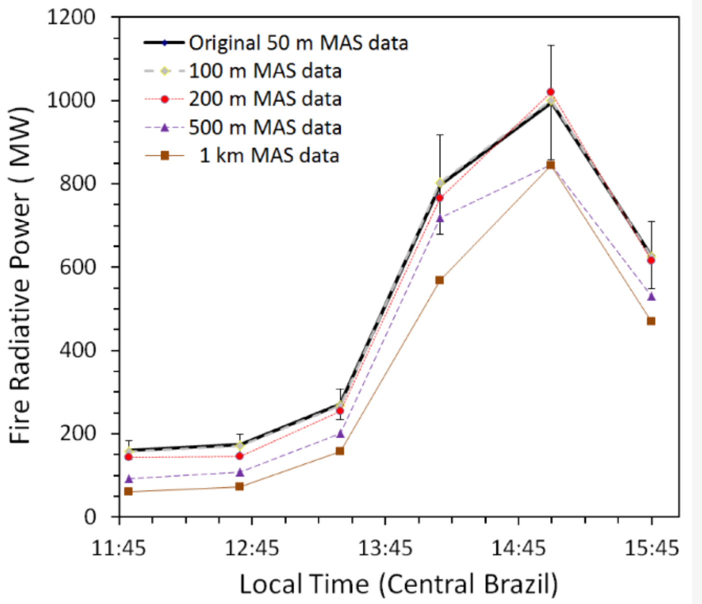
- Approaches to best convert from FRP or FRE data into fuel consumption and/or fire emissions estimates are still subject of ongoing research (all require some knowledge of emissions factors).
  - Approaches using matched FRP and trace gas data of plumes appear most direct and contain fewest assumptions, but require careful curation of datasets and not all fire types may have appropriate plumes in currently available data.

Single measure to move us closer to what is burned

- Higher spatial resolution geostationary FRP data at high temporal resolution
  (e.g. Meteosat Third Gen soon will offer current best @ 1 to 2 km nadir point FRP data every 2.5 to 10 mins)

- Supplemented by regular FRP data from high spatial resolution polar orbiters at higher latitudes (VIIRS or slightly better pixel size is possibly good enough)





Sperling et al. (2020)

- Higher spatial resolution sensors for trace gas retrievals within plumes (e.g. higher resolution Sentinel 5P type capability, ideally including CO_2 retrieval).