

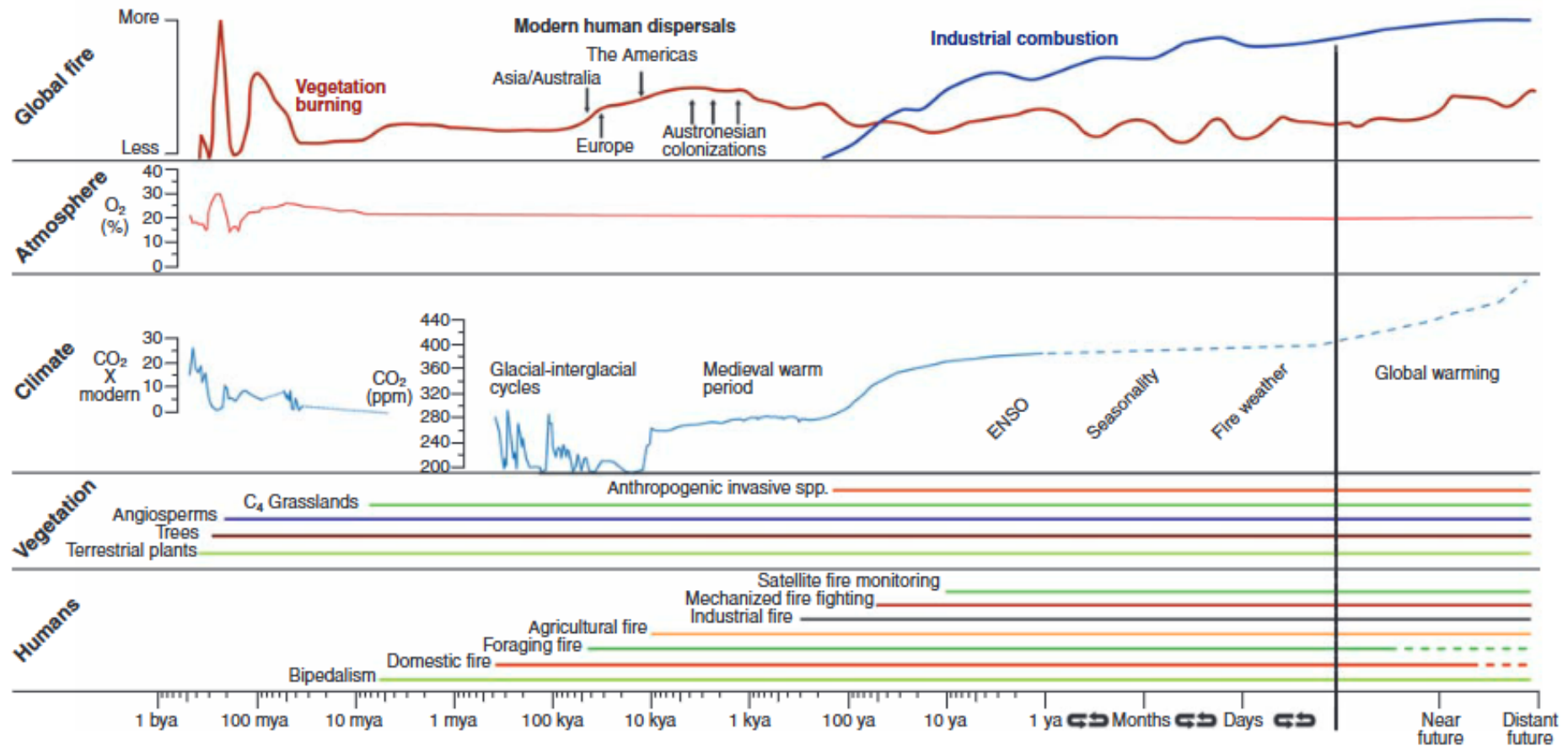
What can remote sensing tell us about wildfires?

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Fire in the Earth System

- Present on Earth since the appearance of terrestrial plants.
- Humans have been using fire for more than 50,000 years.



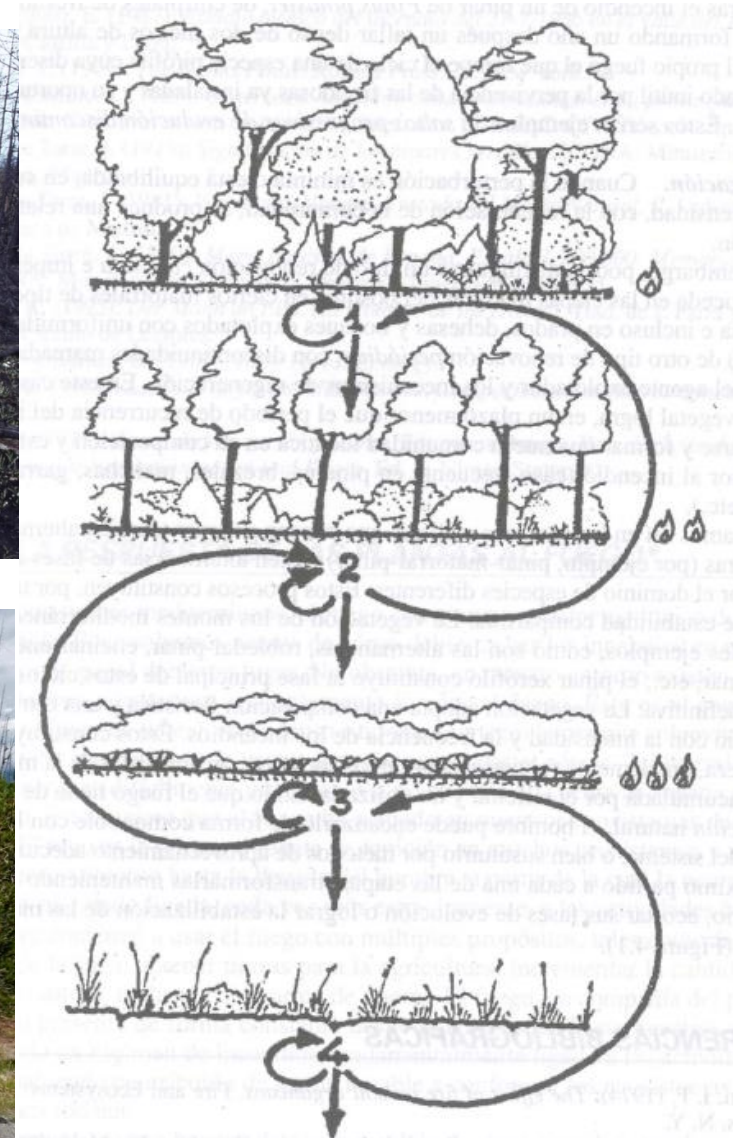
Fire effects

Ecological effects:

- Species selection (*Pinus canariensis*)
- Plant reproduction (*Pinus*, *Cistus*, *Eucalyptus*, etc.)
- Grass regeneration
- Vegetation transition due to shifts in natural fire regimes.



Yellowstone (USA) fires of 1988



García Novo, F. (1977).

Fire effects

Other effects:

- Gasses and particular matter release: impacts on human health and climate emissions.
- Soil erosion and siltation of water reservoirs.
- Changes in surface albedo.
- Life risk and losses due to fires, both to firefighters and general population.
- Material losses (houses, infrastructures, ecosystem services).



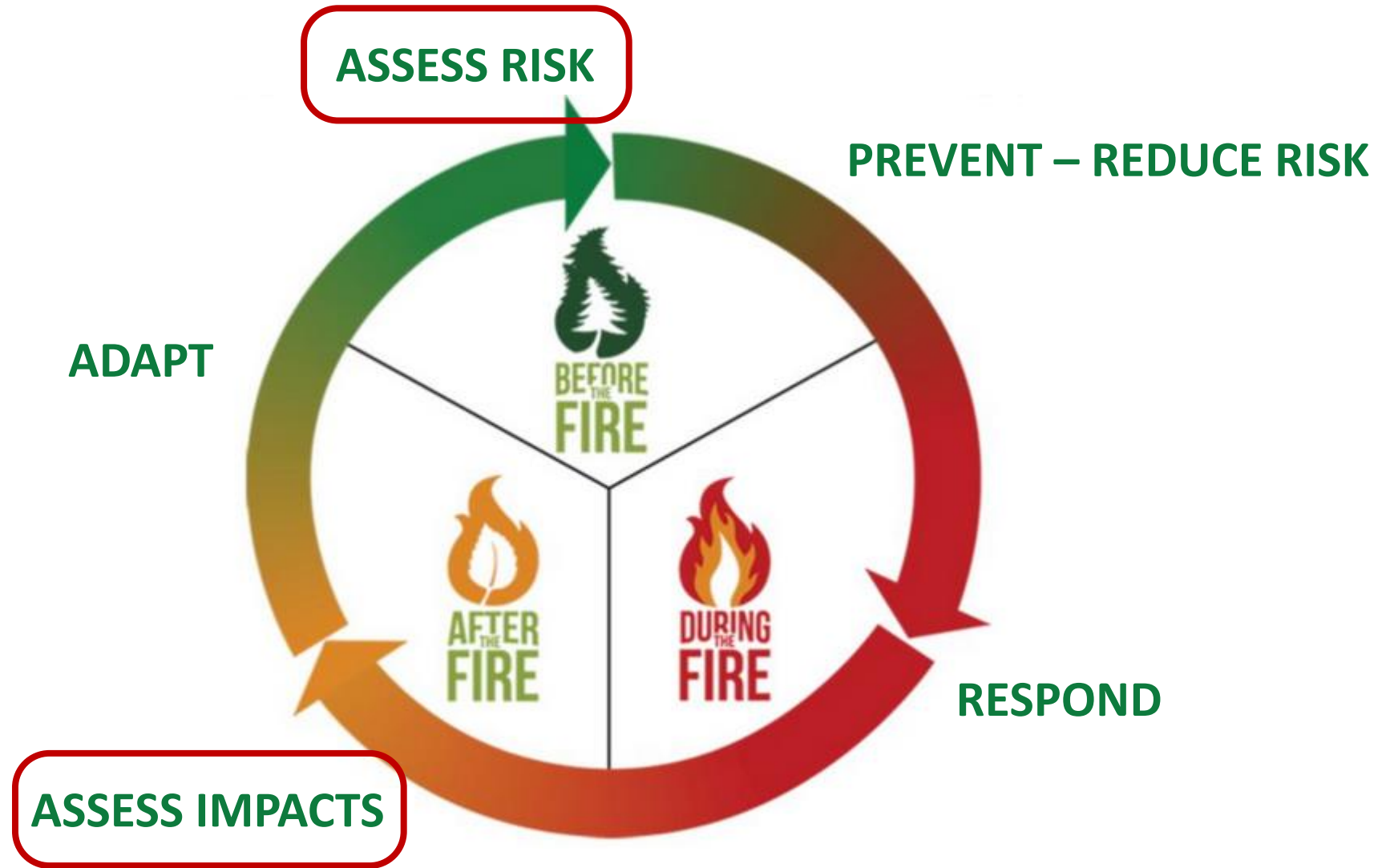
Haze in Kuala Lumpur



Fires in Indonesia of 2015.

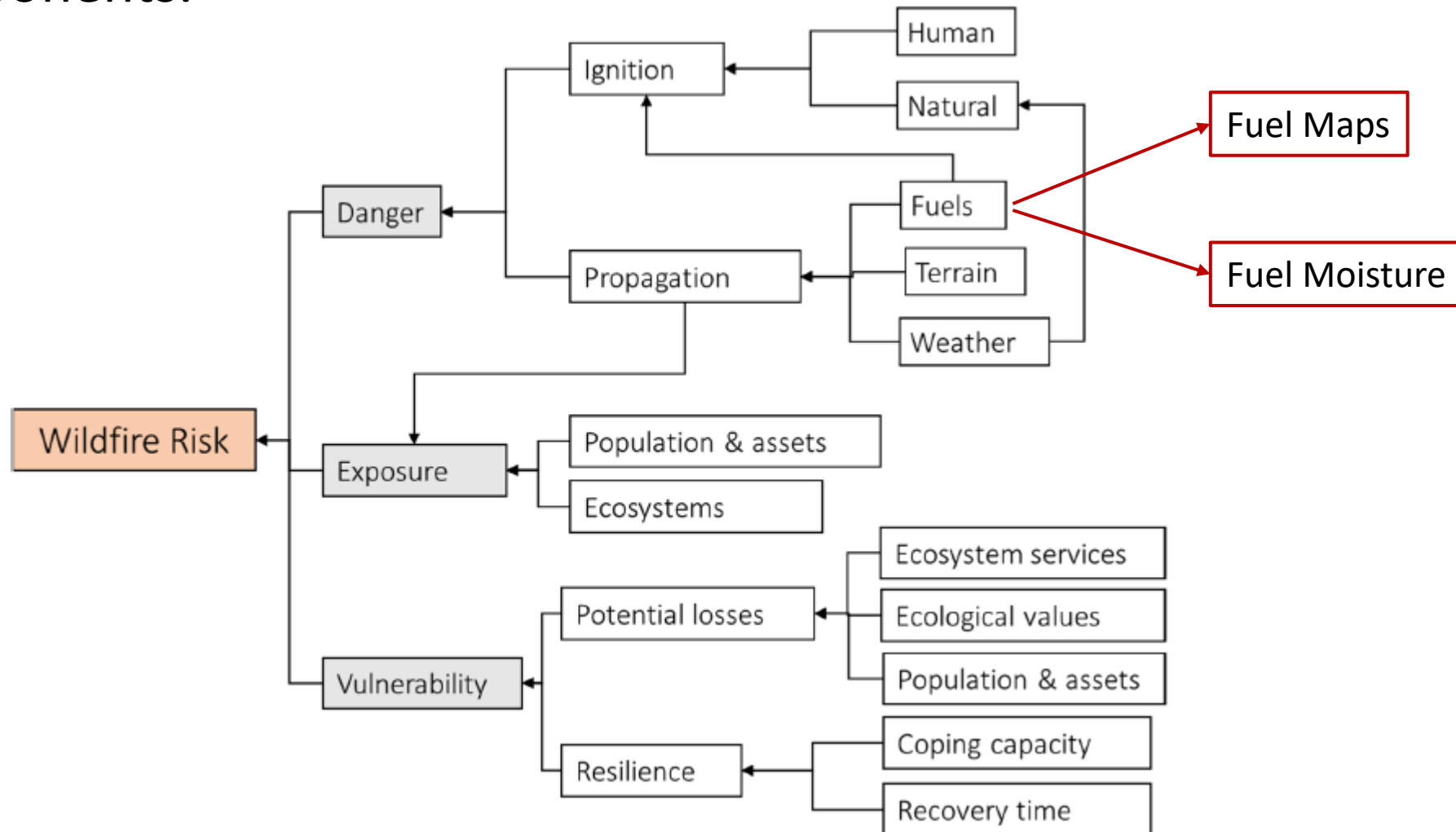


The fire cycle



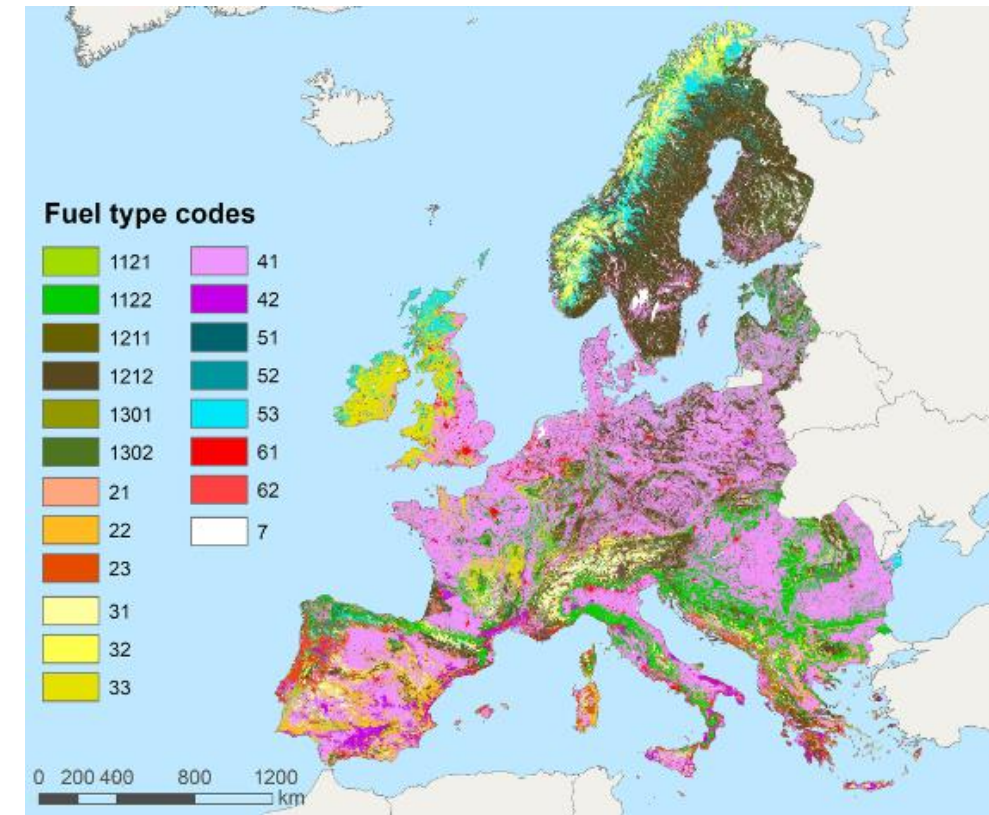
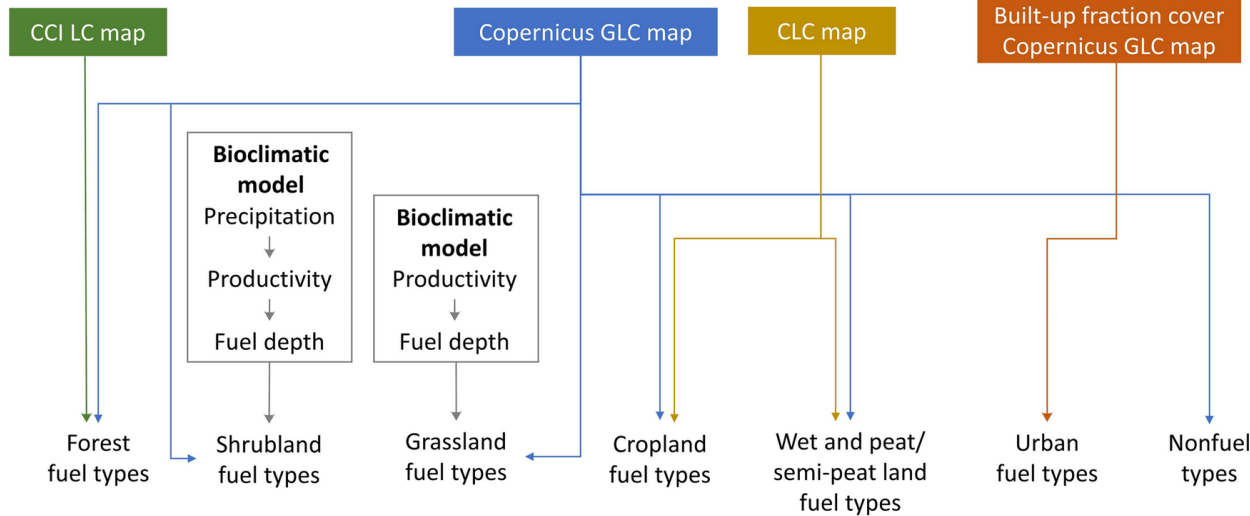
Wildfire Risk Assessment

- FirEUrisk – Conceptual integration of wildfire risk assessment components.



Wildfire Risk Assessment

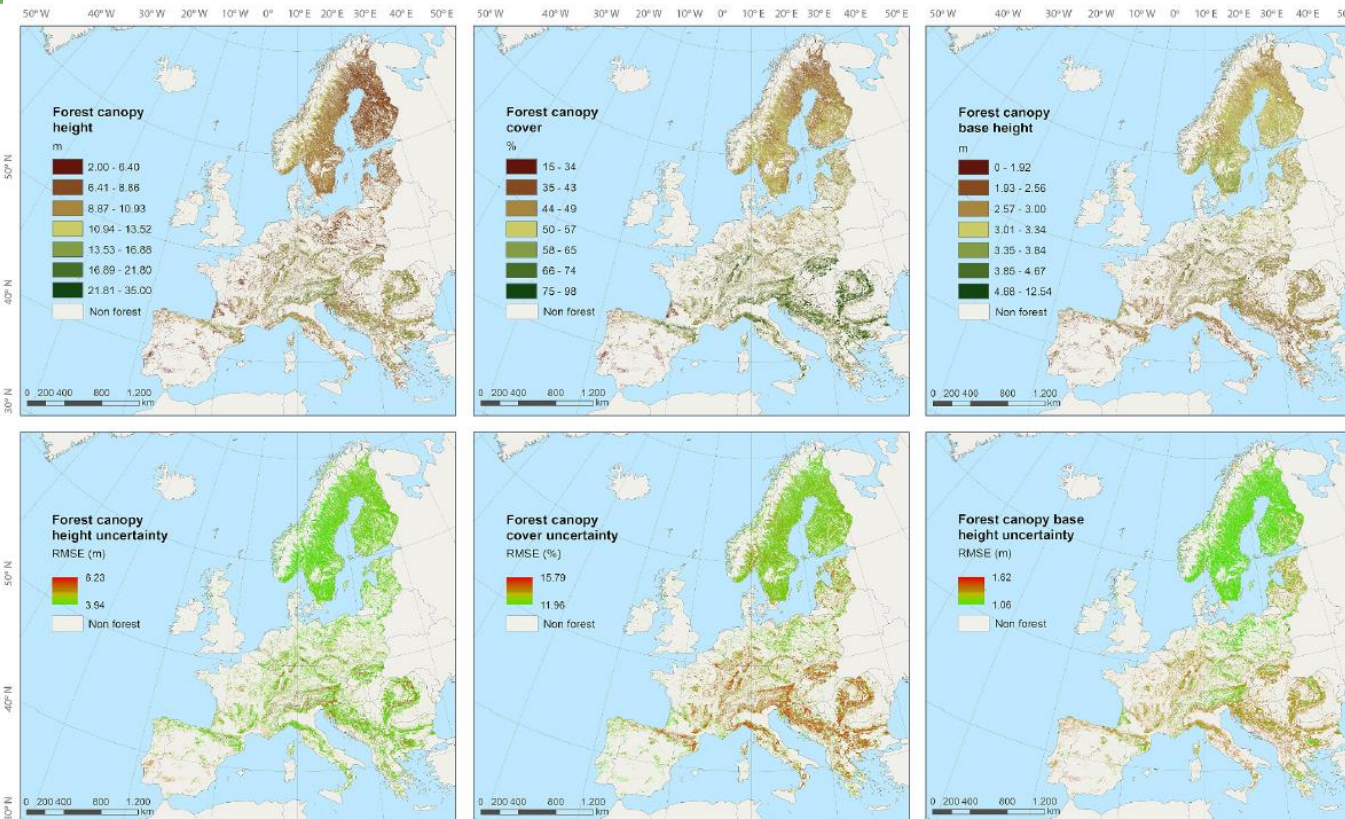
- Fuel mapping: development of a fuel classification for Europe, and mapping of those fuel models.



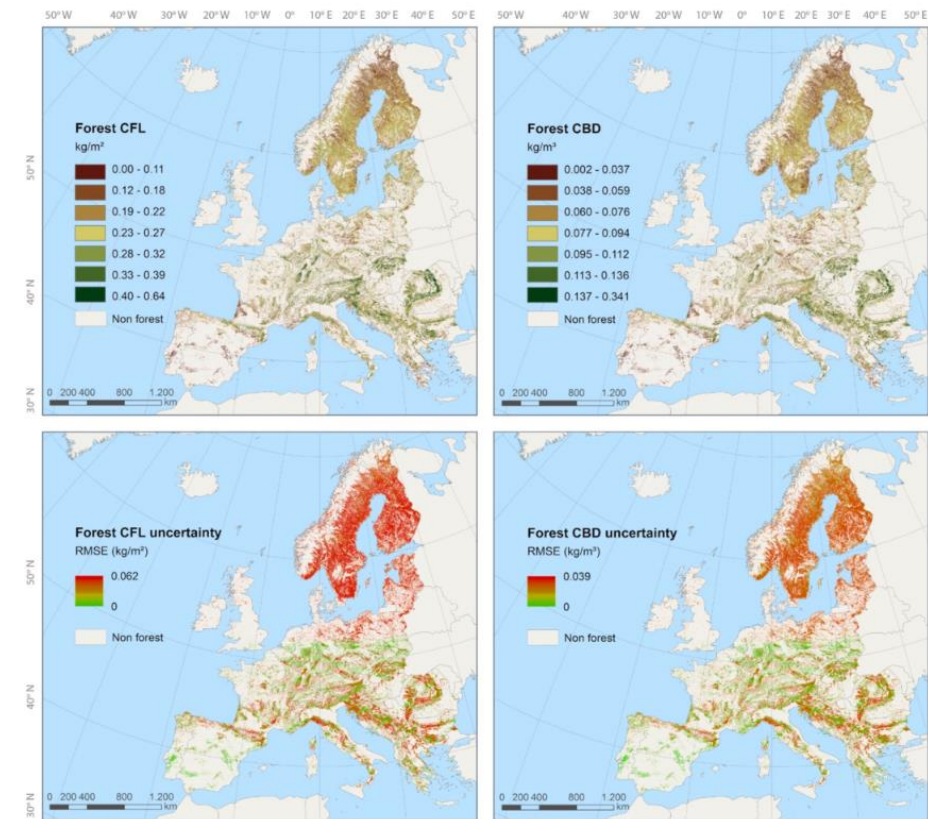
FirEURisk fuel type		FirEURisk fuel type	
Code	Description	Code	Description
1111	Open broadleaf evergreen forest	23	High shrubland (≥ 1.5 m)
1112	Closed broadleaf evergreen forest	31	Low grassland [0–0.3 m)
1121	Open broadleaf deciduous forest	32	Medium grassland [0.3–0.7 m)
1122	Closed broadleaf deciduous forest	33	High grassland [≥ 0.7 m)
1211	Open needleleaf evergreen forest	41	Herbaceous cropland
1212	Closed needleleaf evergreen forest	42	Woody cropland
1221	Open needleleaf deciduous forest	51	Wet and peat/semi-peat land – tree
1222	Closed needleleaf deciduous forest	52	Wet and peat/semi-peat land – shrubland
1301	Open mixed forest	53	Wet and peat/semi-peat land – grassland
1302	Closed mixed forest	61	Urban continuous fabric
21	Low shrubland [0–0.5 m)	62	Urban discontinuous fabric
22	Medium shrubland [0.5–1.5 m)	7	Nonfuel

Wildfire Risk Assessment

- Fuel mapping: fuel canopy parameters estimated from GEDI data, modelled from ALS inventories, National Forest Inventories, multispectral and SAR imagery, and biophysical variables.



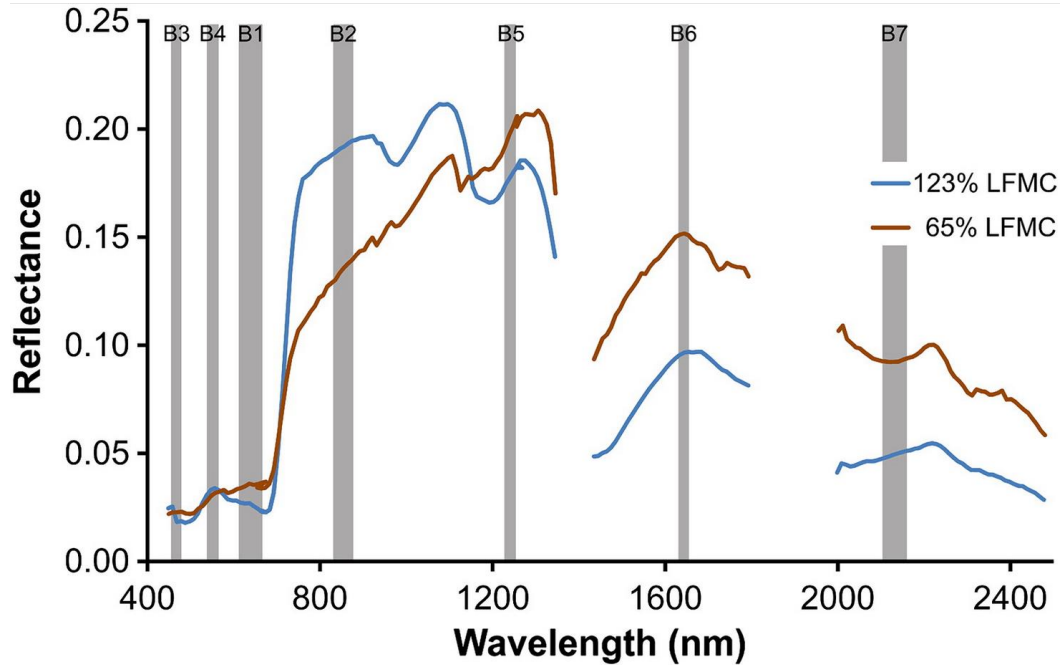
Aragoneses et al. (2024), DOI: 10.1016/j.rse.2024.114005



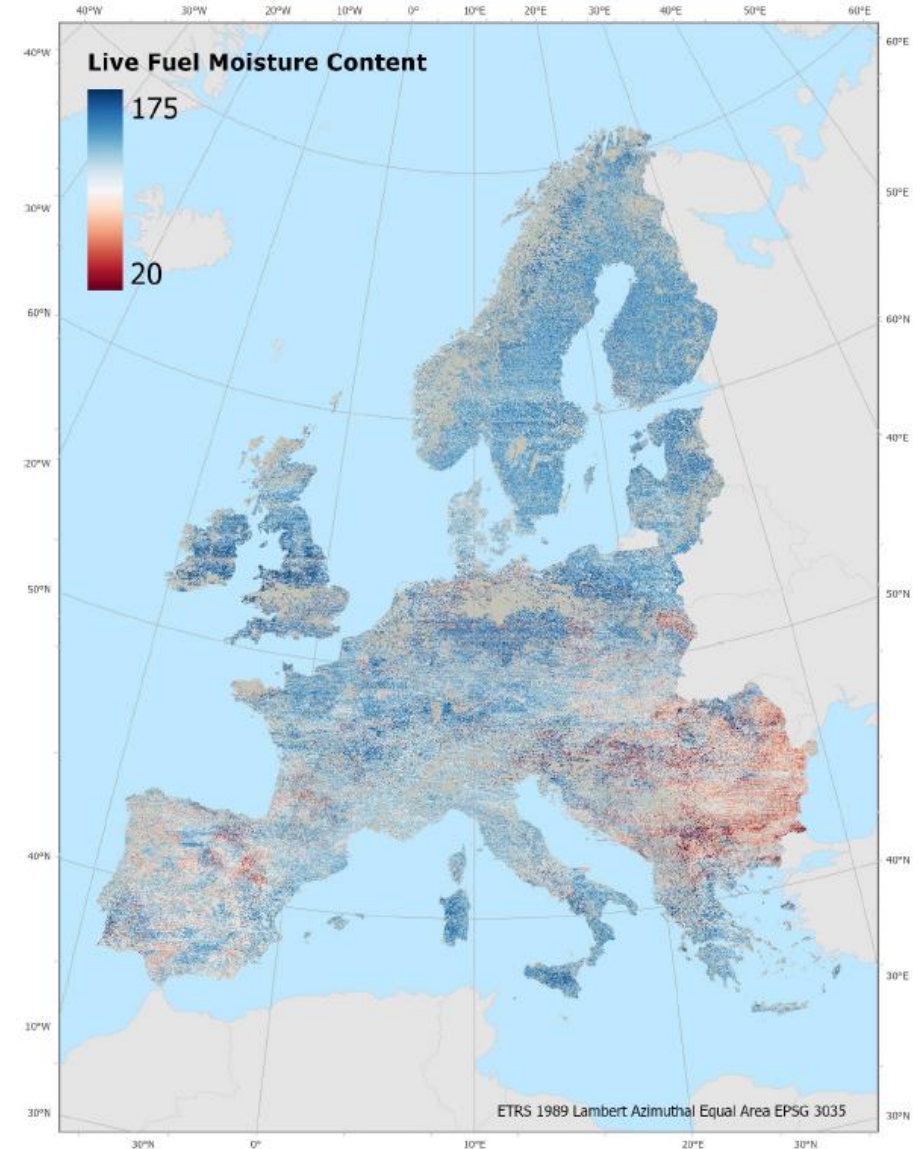
Aragoneses et al. (2025), DOI: 10.1016/j.rse.2024.114578

Wildfire Risk Assessment

- Fuel moisture: Live Fuel Moisture Content derived from optical remote Sensing (NIR-SWIR bands) and Radiative Transfer Models (RTM), using Look-up tables.

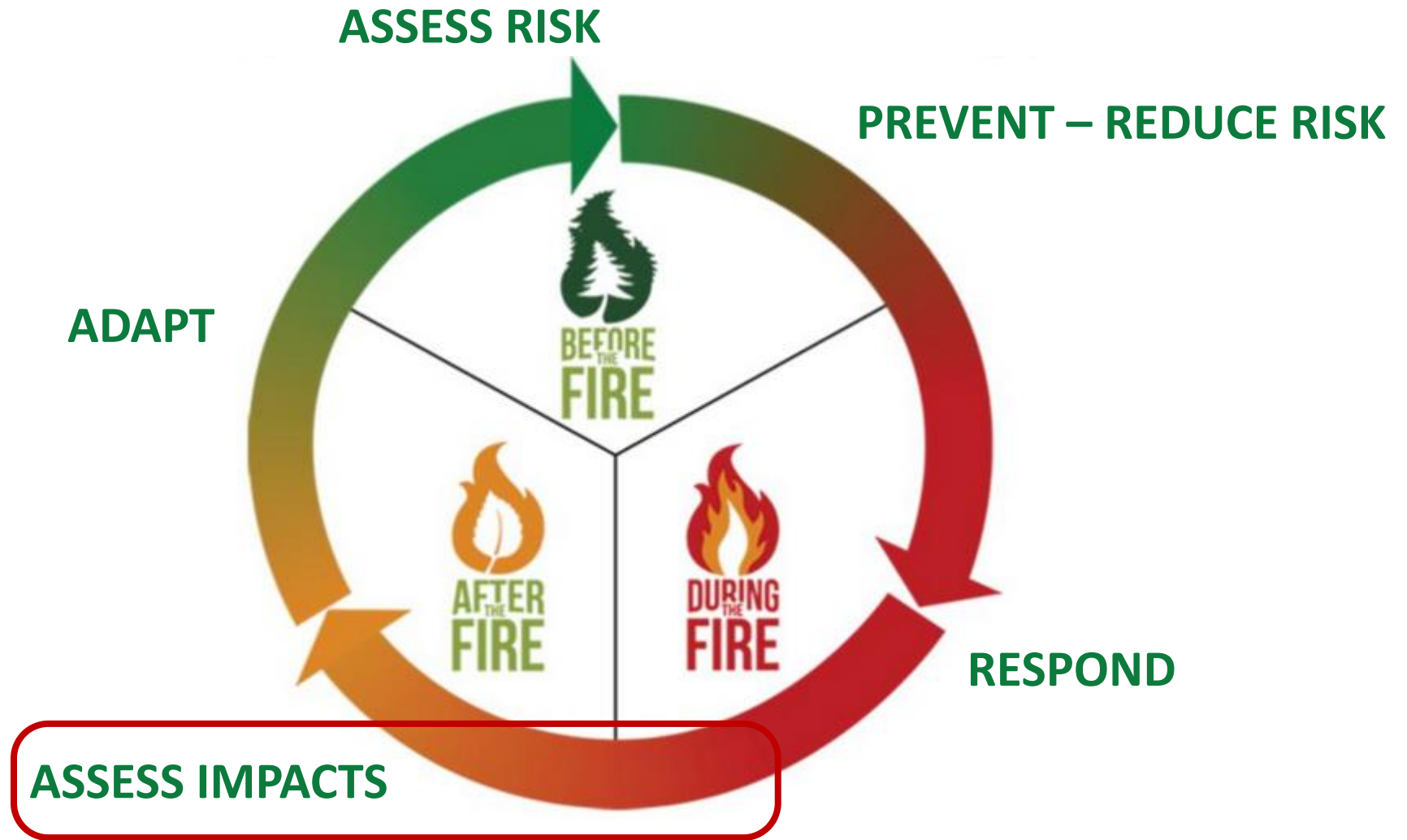


Yebara et al. (2013), DOI: 10.1016/j.rse.2013.05.029



Sentinel-3 based LFM in the European Territory on 8 March 2023. Chuvieco et al. (2021), DOI: 10.3390/fire6050215

The fire cycle



Detecting the location and extent of fires

- During the fire → thermal anomalies, active fires (AF), hotspots (HS)
- After the fire → burned area



Remote sensing of active fires

Wavelengths most commonly used:

- SWIR: 1.6 μm , 2.2 μm
- MIR (Middle Infrared): 3.7 – 4.0 μm
- TIR (Thermal Infrared): 10.5 – 11.0 μm

The sensor captures the temperature of the pixel, in $^{\circ}\text{K}$. MIR and TIR information are used to identify the pixels that have thermal anomalies.

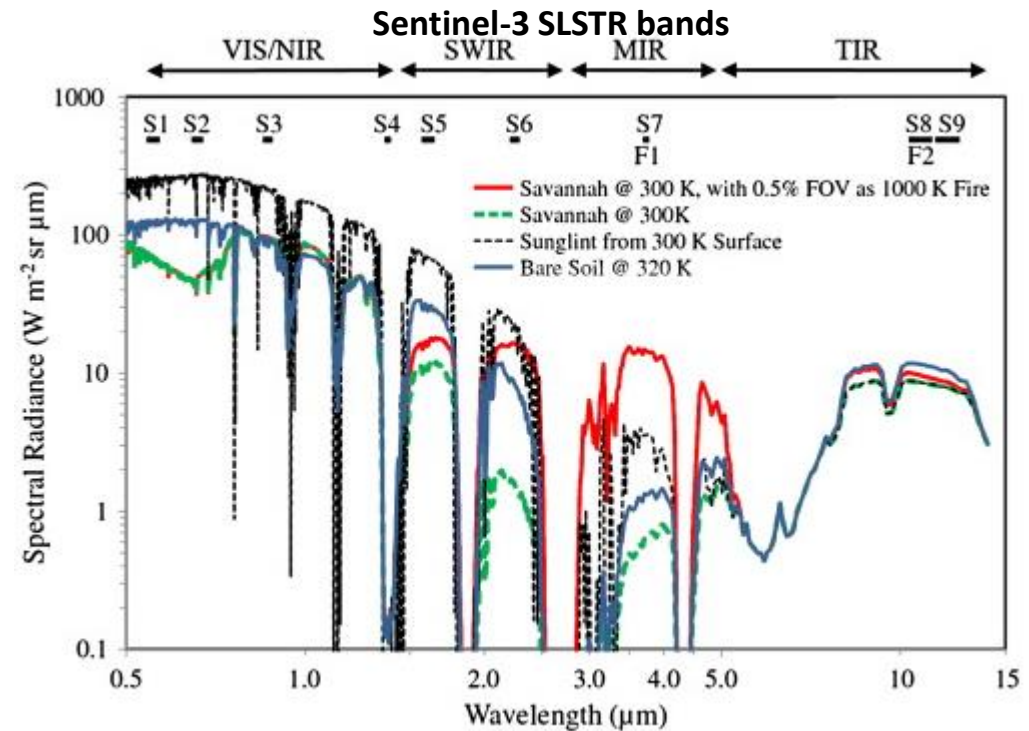
The energy released by the fire can be estimated as the Fire Radiative Power [MW] based on the MIR radiance.

$$FRP = \frac{A_{\text{sampl}}}{10^6 \cdot \tau_{\text{MIR}}} \left(\frac{\sigma}{a} \right) (L_{\text{MIR}} - \bar{L}_{\text{MIR}}) \text{ [MW]}.$$

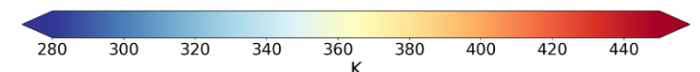
S3 SLSTR - Wooster et al. (2012),
DOI: 10.1016/j.rse.2011.09.033

$$FRP_{\text{MR}} = \frac{A_{\text{sampl}} \sigma \epsilon}{\alpha \epsilon_{\text{MIR}}} L_{\text{MIR}}$$

MTG FCI - Xu et al. (2026), DOI:
10.1016/j.srs.2026.100366



Wooster et al. (2012), DOI: 10.1016/j.rse.2011.09.033



Fire in Aveiro – Source: EUMETSAT

Remote sensing of active fires

MODIS: Moderate Resolution Imaging Spectroradiometer

- Satellites: Terra and Aqua
- Spatial resolution: 1000 m
- Time series: end of 2000 to 2026

VIIRS: Visible Infrared Imaging Radiometer Suite

- Satellites: Suomi-NPP, NOAA-20, NOAA-21.
- Spatial resolution: 375 & 750 m
- Time series: 2012 to present

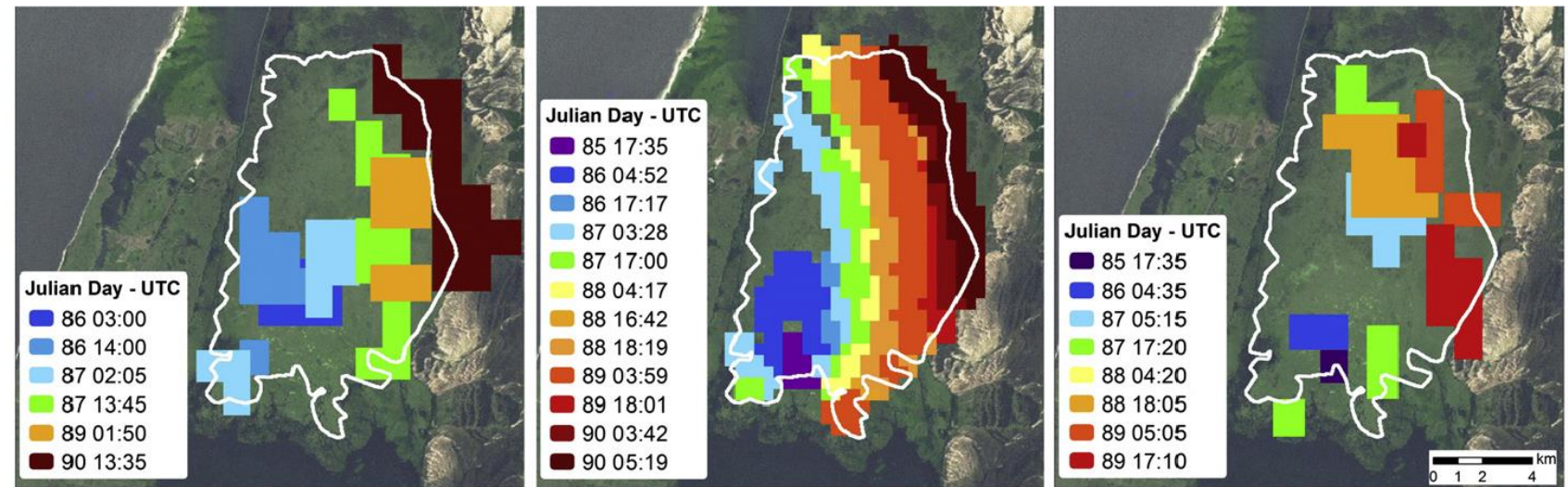
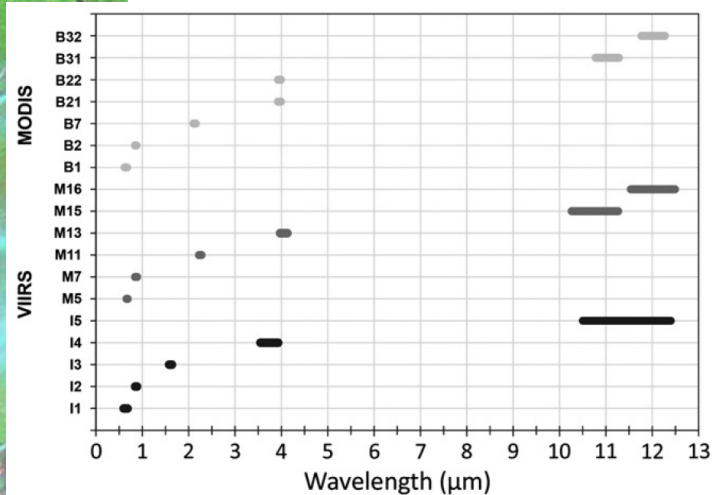


Fig. 9. Daily fire spread mapped by 1 km Terra/MODIS (left), 375 m VIIRS (center), and 1 km Aqua/MODIS (right) data for a wildfire at the Taim Ecological Reserve in southern Brazil (-32.7°lat , -52.55°lon). The data cover the period beginning on 26 March 2013 (Julian day 85) and ending at the approximate time of the Landsat-7 data acquired at 13:15UTC on 31 March 2013. The white vector outline represents the burned area mapped using the 30 m Landsat-7 data.

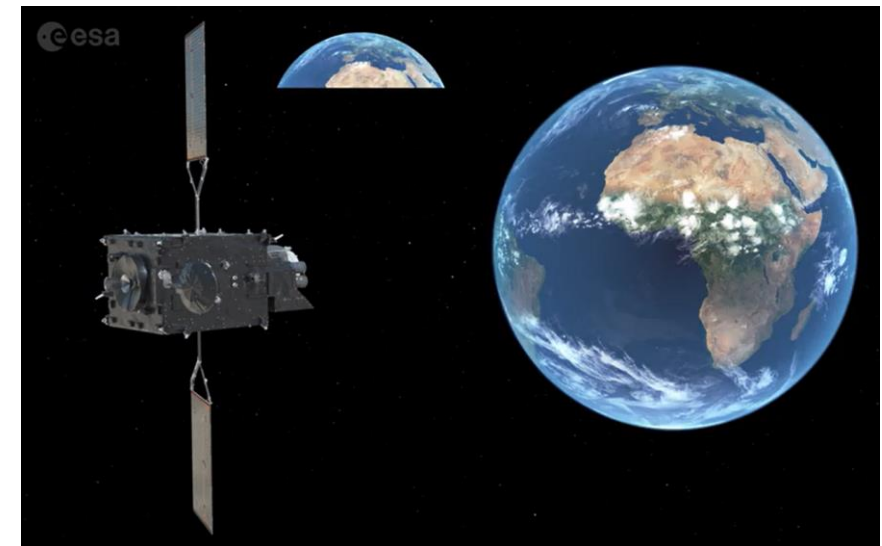
Remote sensing of active fires

FCI: Flexible Combined Imager

- Satellites: Meteosat Third Generation (MTG) - geostationary
- Detections every 10 min over the full disk, and 2.5 min over Europe, in the High Resolution Fast Imagery (HRFI) mode.

Satellite Sensor	Spectral Band Number	Wavelength Range (μm)	Spatial Sampling Distance at SSP (km)	Primary Use in Active Fire Detection and FRP Retrieval Scheme
MTG (FCI)	3	0.56–0.62	(0.5 and 1)	Cloud masking
	9	3.74–3.94	(1 and 2)	Active fire detection & FRP retrieval
	14	10.28–10.72	(1 and 2)	Active fire detection & Cloud masking

Xu et al. (2026), DOI: 10.1016/j.srs.2026.100366



Source: ESA



Remote sensing of active fires

Advantages:

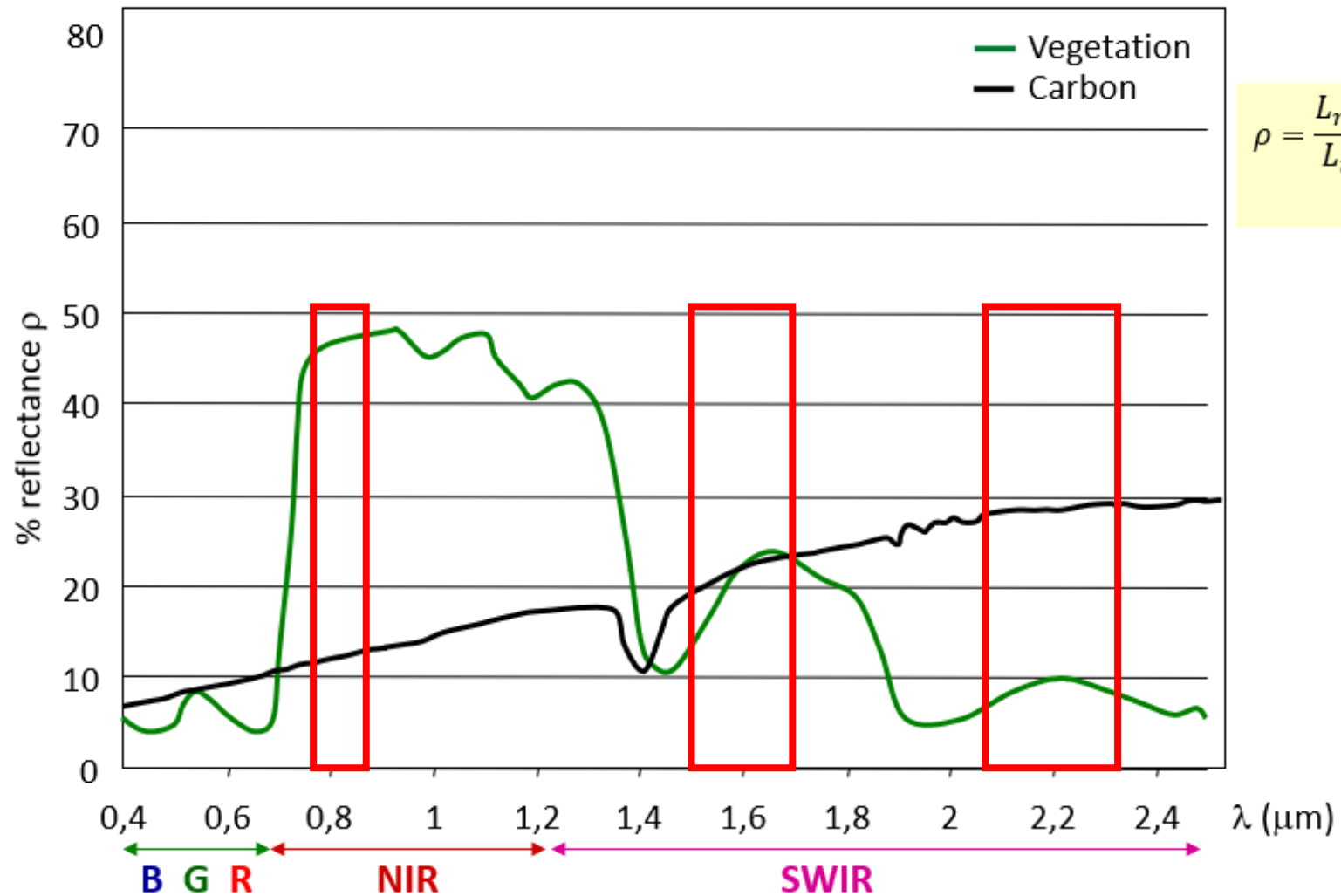
- It can detect active fires both during the day and at night.
- It provides information about the intensity of the fire through the FRP values.

Challenges:

- For polar satellites (the ones used for global applications), it can only detect the fire if it is flaming at the moment of overpass of the satellite (and it can be obscured by clouds).
- The thermal anomalies can be due to other sources different from fires (gas flares, industries, etc.).

Remote sensing of burned areas

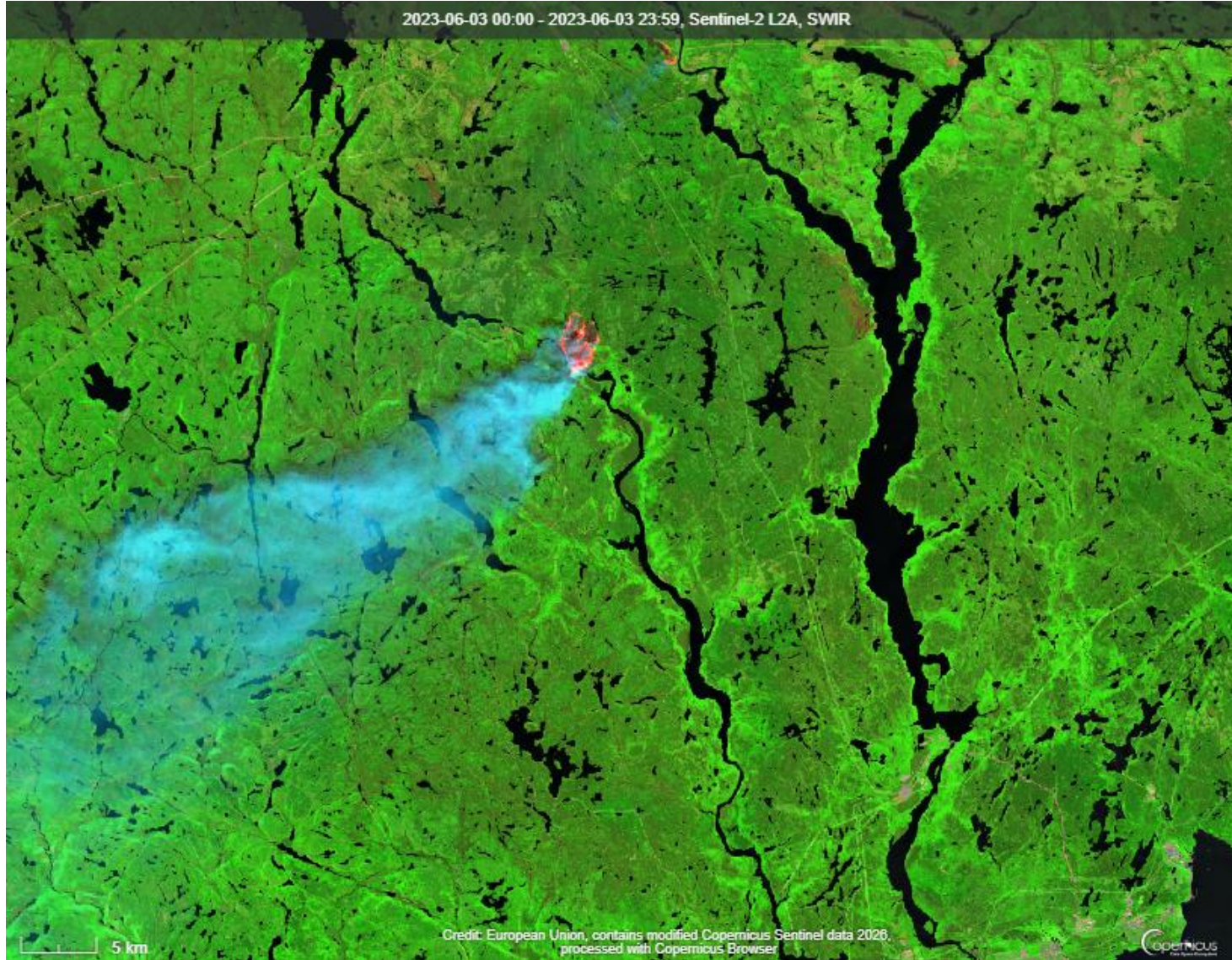
- Best wavelengths for detecting fires:



$$\rho = \frac{L_{reflected}}{L_{incident}}$$

Remote sensing of burned areas

- Best wavelengths for detecting fires:



Eastern Canada

June 2023

SWIR-NIR-R Composite

Remote sensing of burned areas

Typical algorithms:

- Analyse changes in surface reflectance between pre and post-fire conditions
- Use single band reflectances or spectral indices (or both) to discriminate between burned and not burned pixels
- Also use active fires to detect clearly burned pixels

Some widely used indices:

- NBR: Normalised Burned Ratio: $(\text{NIR} - \text{SWIR}) / (\text{NIR} + \text{SWIR})$ Key and Benson (1999)
- NBR2: $(\text{SWIR1} - \text{SWIR2}) / (\text{SWIR1} + \text{SWIR2})$ Key and Benson (2006)
- MIRBI: Mid-InfraRed Bispectral Index: $10 * \text{SWIR2} - 9.8 * \text{SWIR1} + 2$ Trigg and Flasse (2010), DOI: 10.1080/01431160110053185
- BAI: Burned Area Index: $1 / ((0.1 - \text{RED})^2 + (0.06 - \text{NIR})^2)$ Chuvieco et al. (2002), DOI: 10.1080/01431160210153129
- BAIS2: Burned Area Index for Sentinel-2

$$BAIS2 = \left(1 - \sqrt{\frac{B06 * B07 * B8A}{B4}} \right) * \left(\frac{B12 - B8A}{\sqrt{B12 + B8A}} + 1 \right)$$

Filipponi (2018), DOI: 10.3390/ecrs-2-05177



Remote sensing of burned areas

Advantages:

- The burn signal persists through time, and it can detect the whole burned scar, several weeks to months after the end of the fire

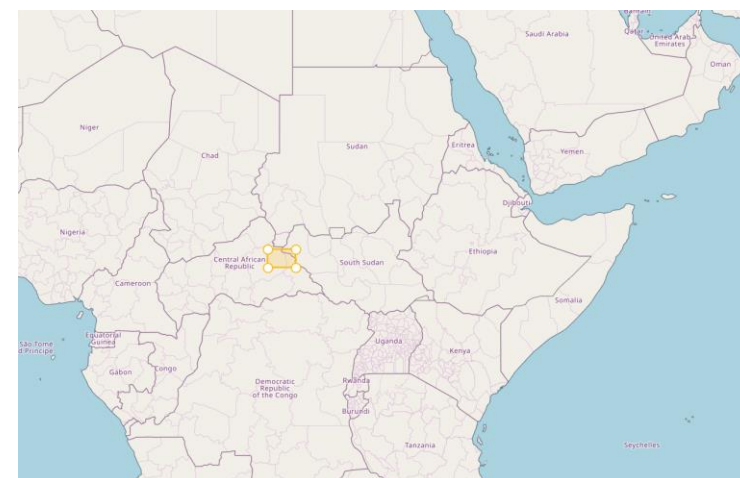
Challenges:

- In some regions of the world (tropical) the burn signal is lost very quickly
- Persistent cloud cover can hamper the detection of burned patches
- Potential confusion with other land changes (flooding, harvesting) or with cloud shadows

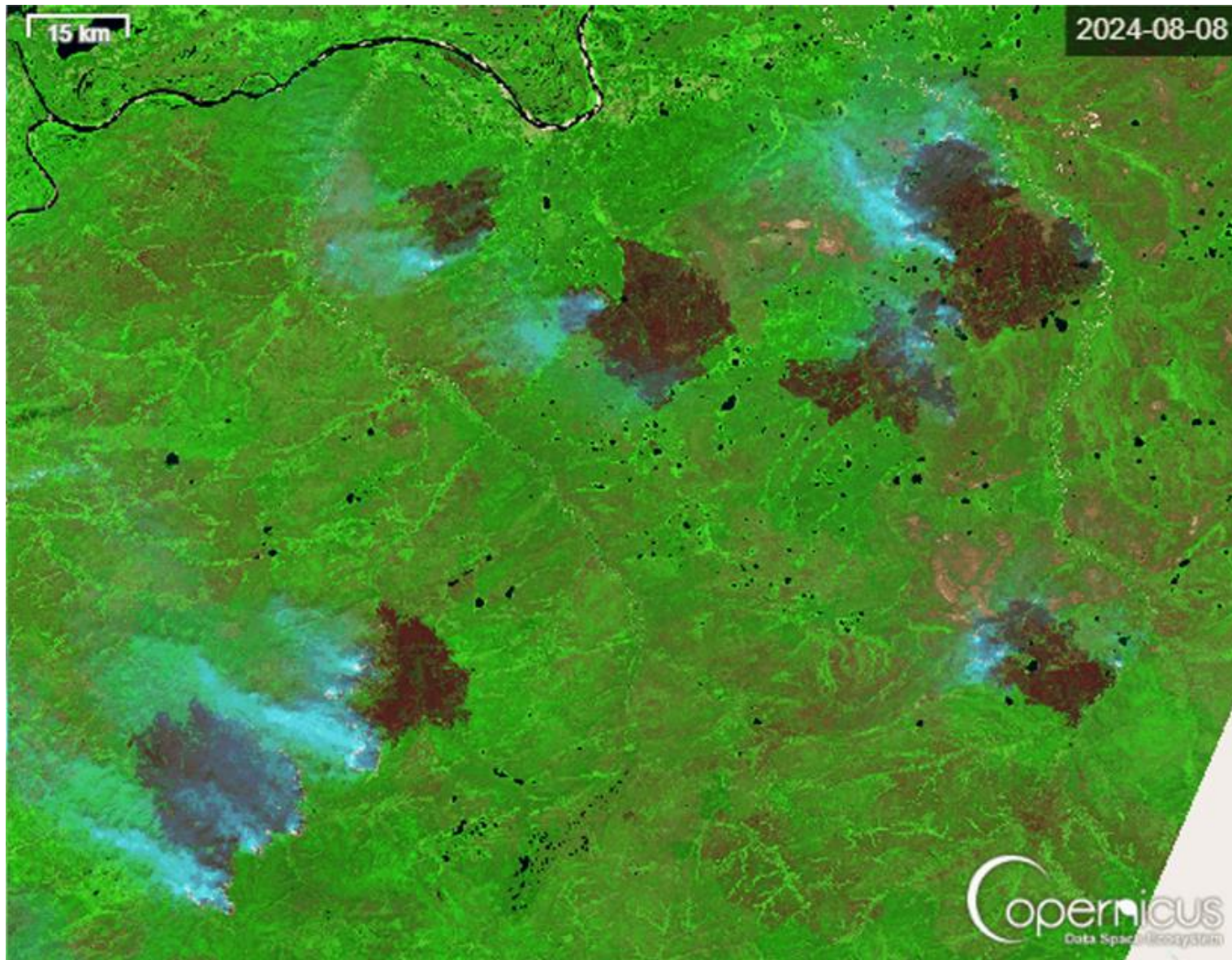
Example of burn scars in the Central African Republic



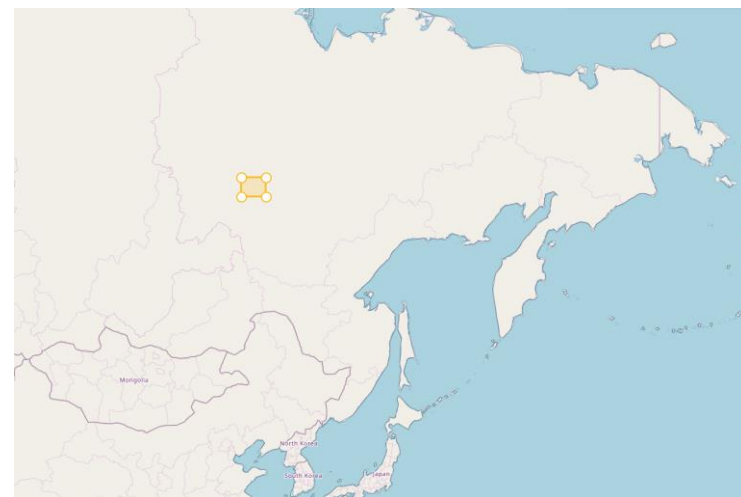
- Central African Republic
- November 2025 – May 2026
- Lat 7.70°, Lon 24°



Example of burn scars in Siberia



- Siberia (Russia)
- June 2024 – August 2025
- Lat 63°, Lon 120.4°



FireCCI medium-resolution global dataset

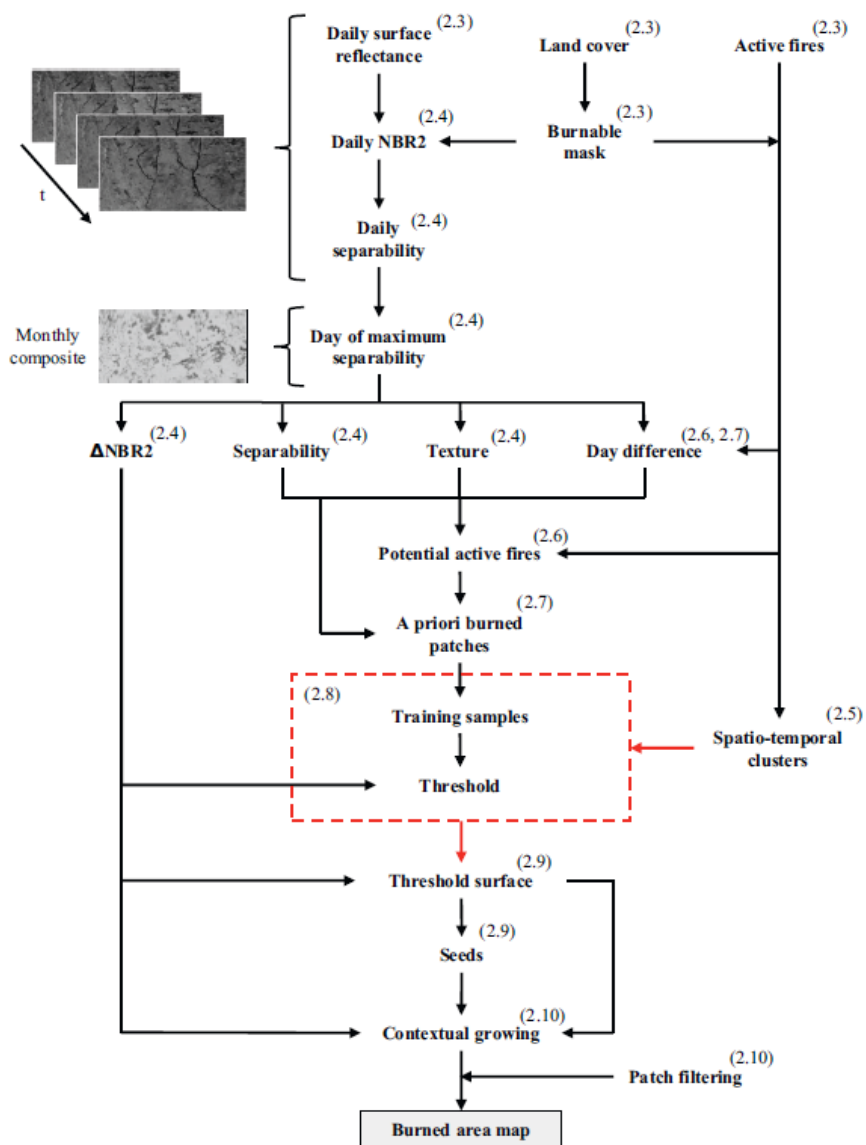


	FireCCI51	MRBA60 (ex FireCCIS311)
Coverage	Global	
Time series	2001-2022	2019-2025...
Pixel resolution	250m	300m
Grid resolution	0.25 deg.	0.25 deg.
Input information	MODIS (SR & HS)	S-3 SYN (SR) + VIIRS (HS)

Lizundia-Loiola et al. (2020) RSE, <https://doi.org/10.1016/j.rse.2019.111493>

Lizundia-Loiola et al. (2022) RSE, <https://doi.org/10.1016/j.rse.2022.113298>

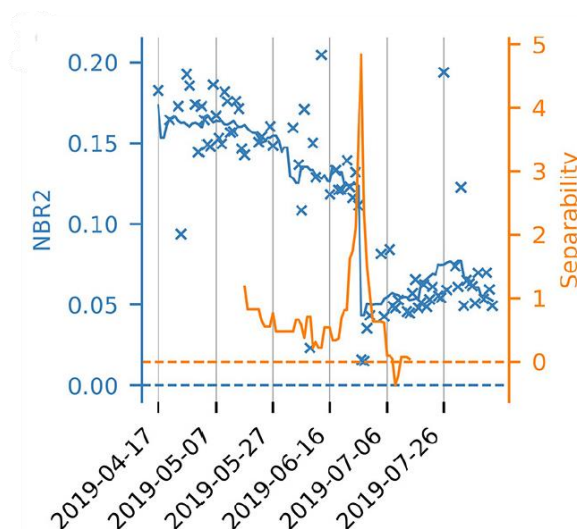
MRBA60 (ex FireCCIS311) algorithm



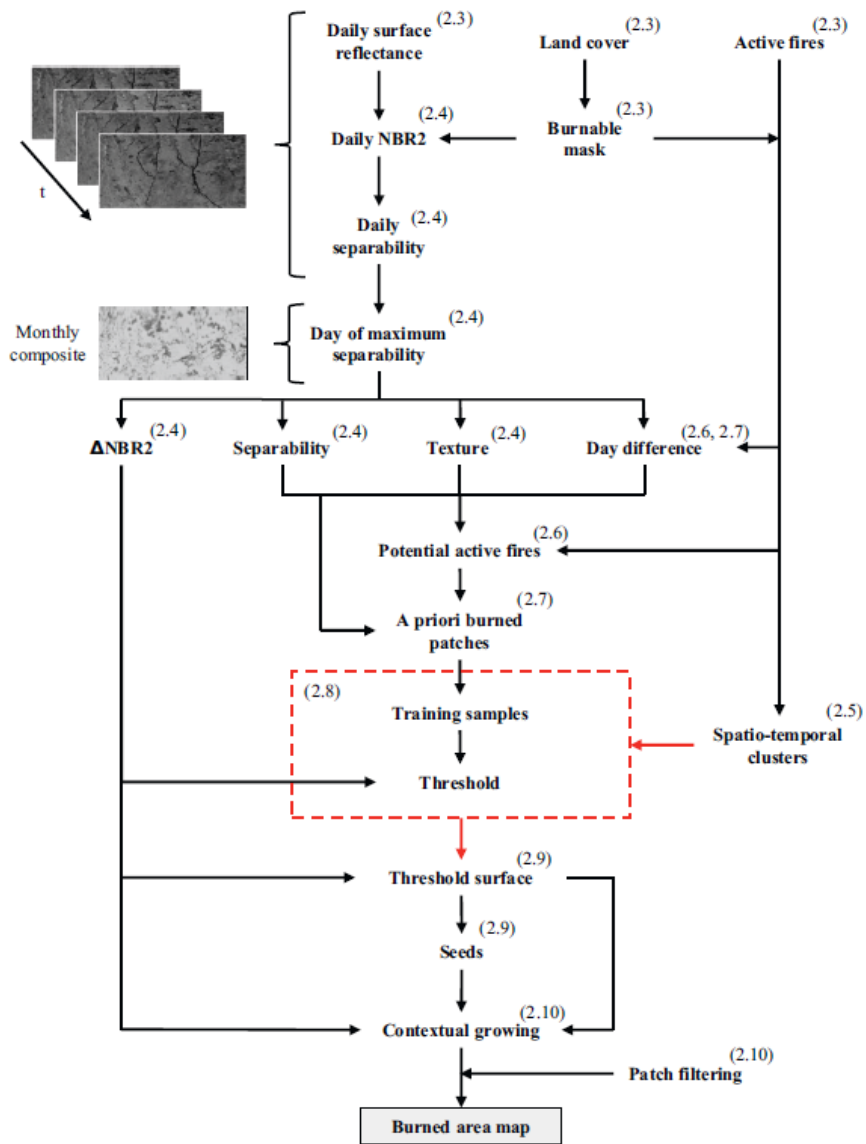
- Monthly composites based on a separability index using 16 daily images per day of calculation.

$$NBR2 = \frac{\rho_{SSWIR} - \rho_{LSWIR}}{\rho_{SSWIR} + \rho_{LSWIR}}$$

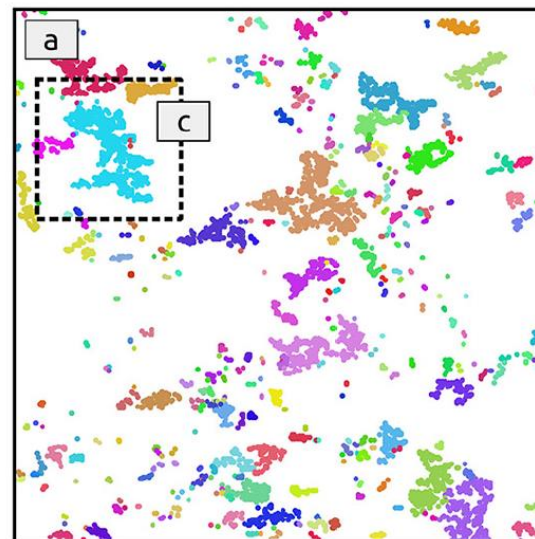
$$S(t, x, y) = \frac{-\Delta NBR2(t, x, y)}{|\sigma_{pre}(t, x, y) + \sigma_{post}(t, x, y)| / 2}$$



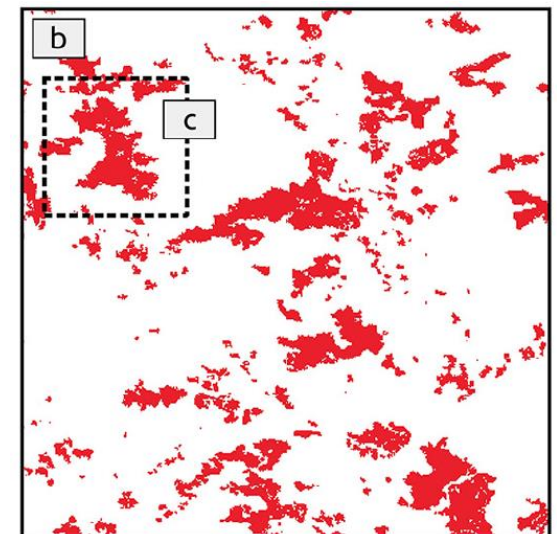
MRBA60 (ex FireCCIS311) algorithm



- Spatio-temporal clusters (STC) based on HS location and day difference.
- Potential Active Fires (PAFs) based on HS location, separability values and day difference.
- A priori burned patches based on PAFs.

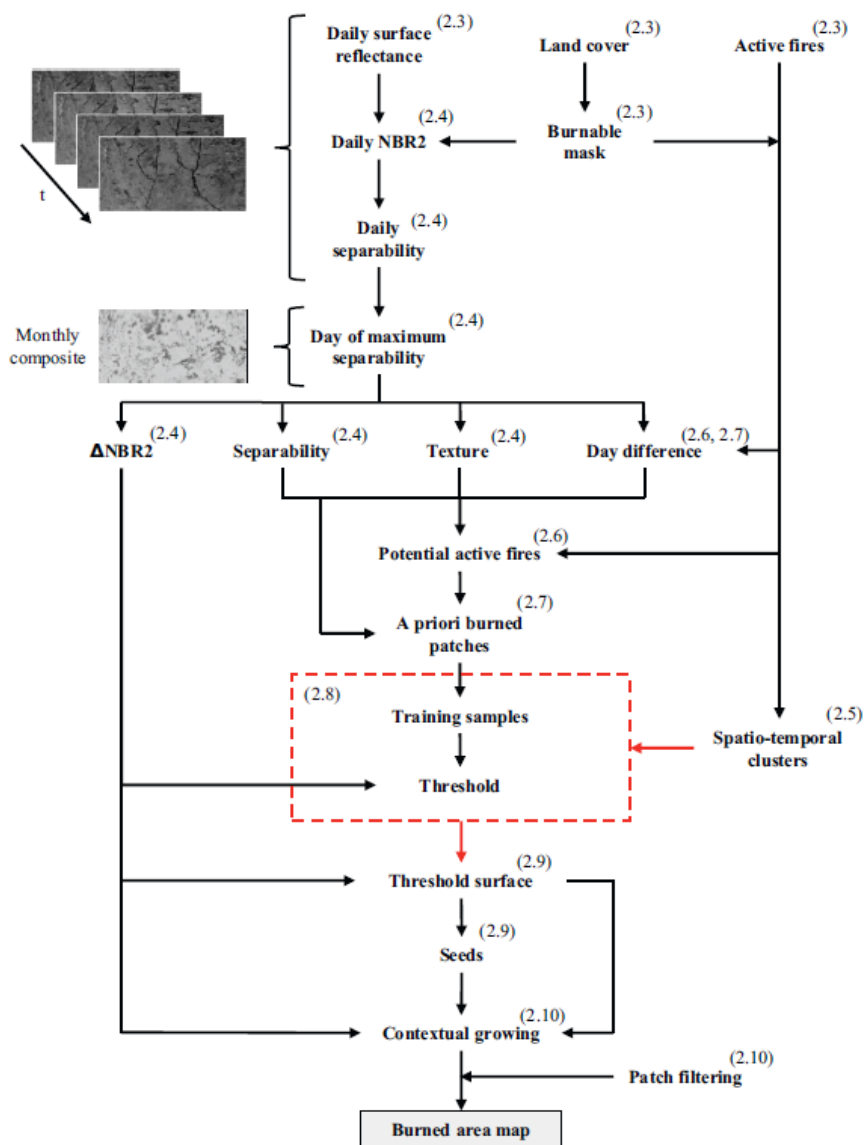


Active fires STC

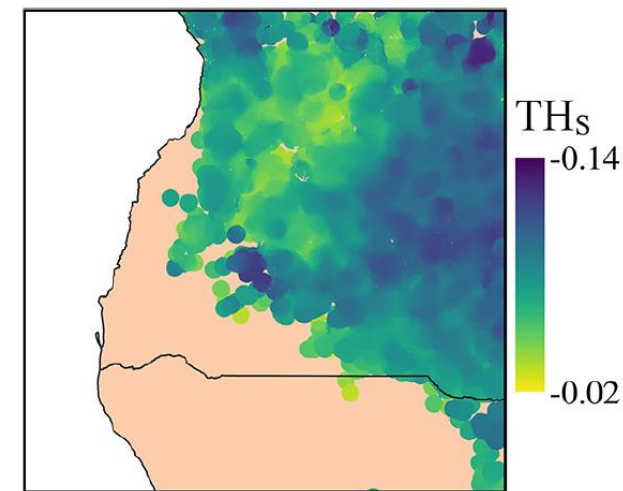
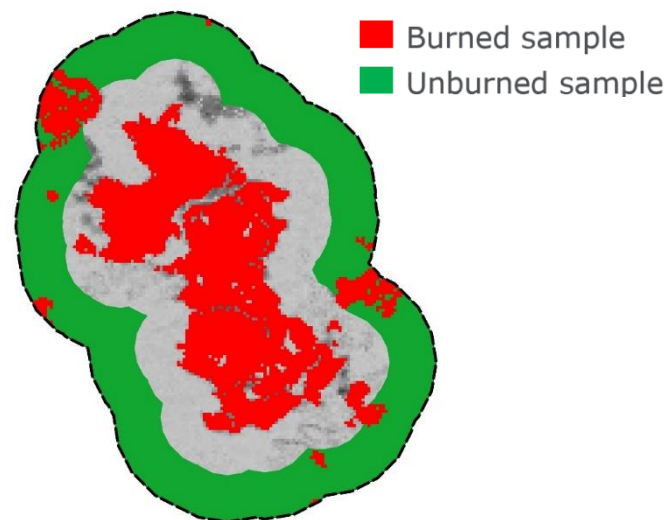


A priori burned patches

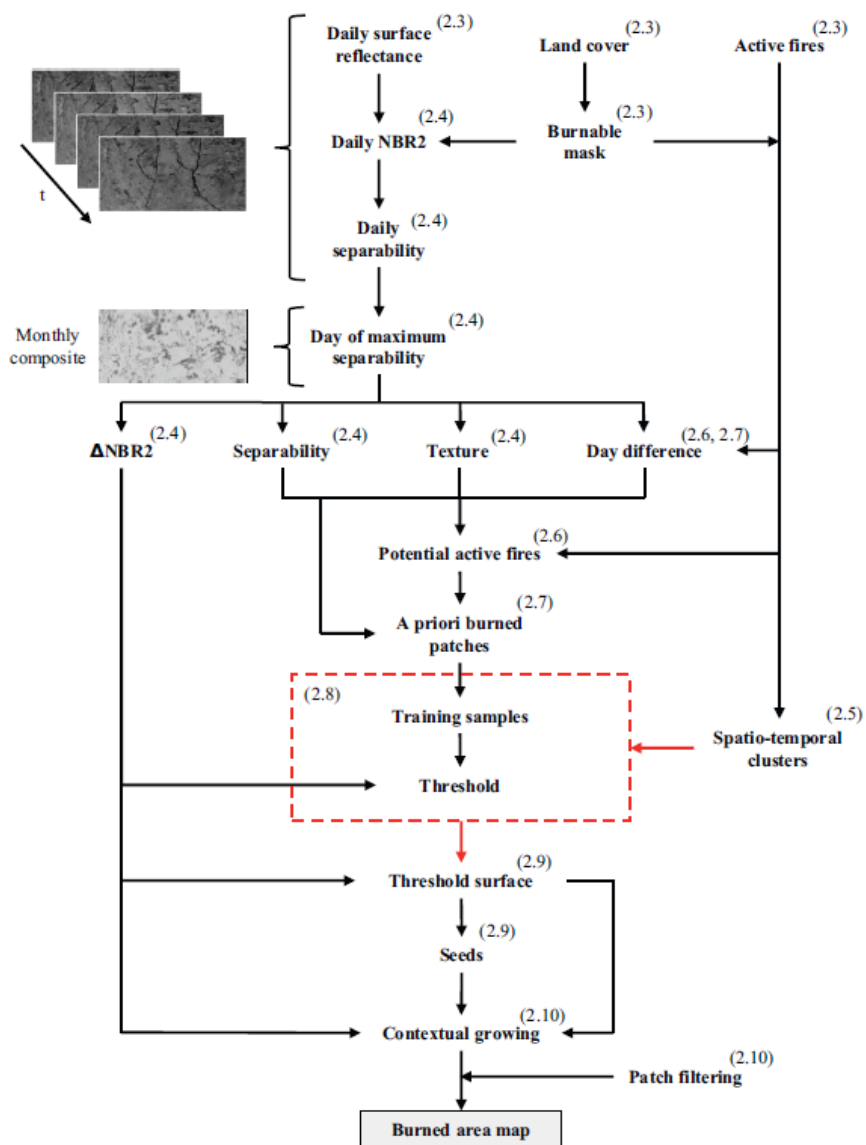
MRBA60 (ex FireCCIS311) algorithm



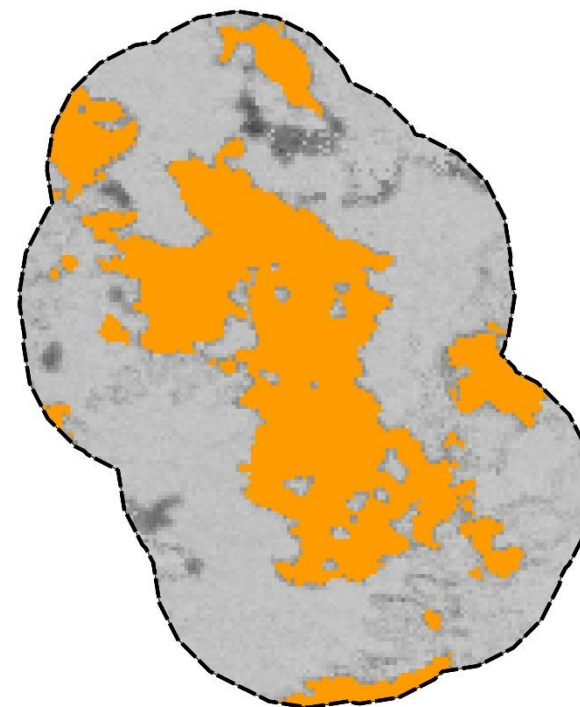
- Definition of unburned (UB) local zones.
- Selection of burned (B) and UB pixels.
- Calculation of B/UB threshold using the Otsu separability method based on ΔNBR2 .
- Threshold surface for the complete tile.



MRBA60 (ex FireCCIS311) algorithm



- Seeds: HS with Δ NBR2 < TH.
- Contextual growing from seeds to detect the full fire patch.
- Formatting to pixel and grid products.

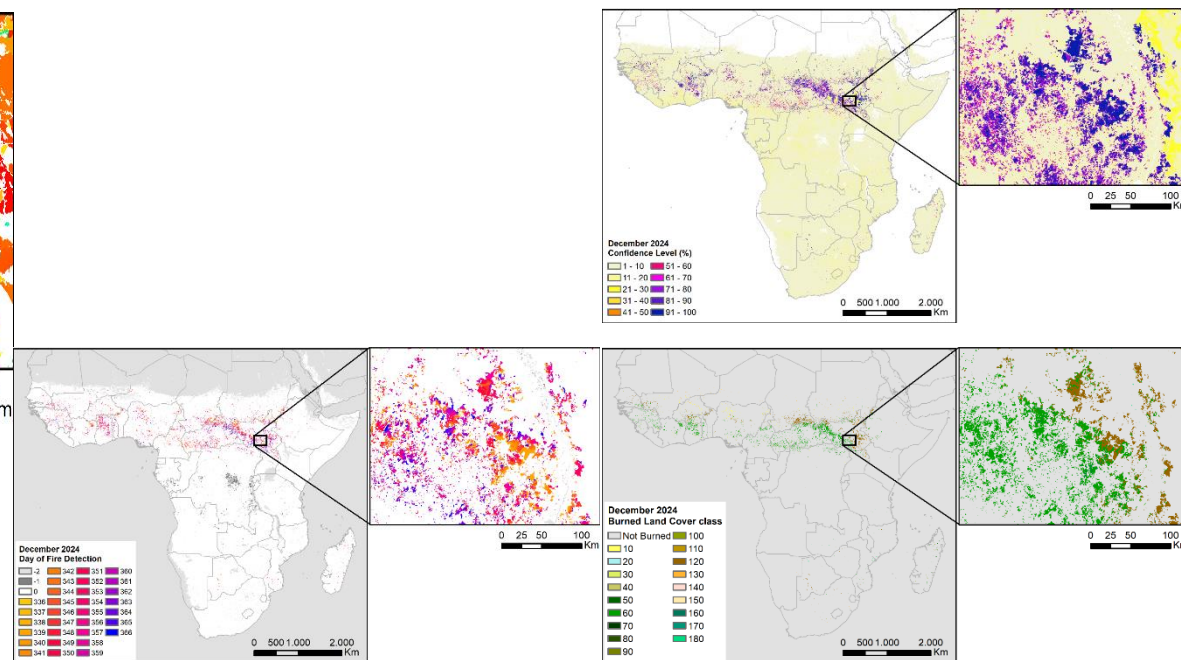
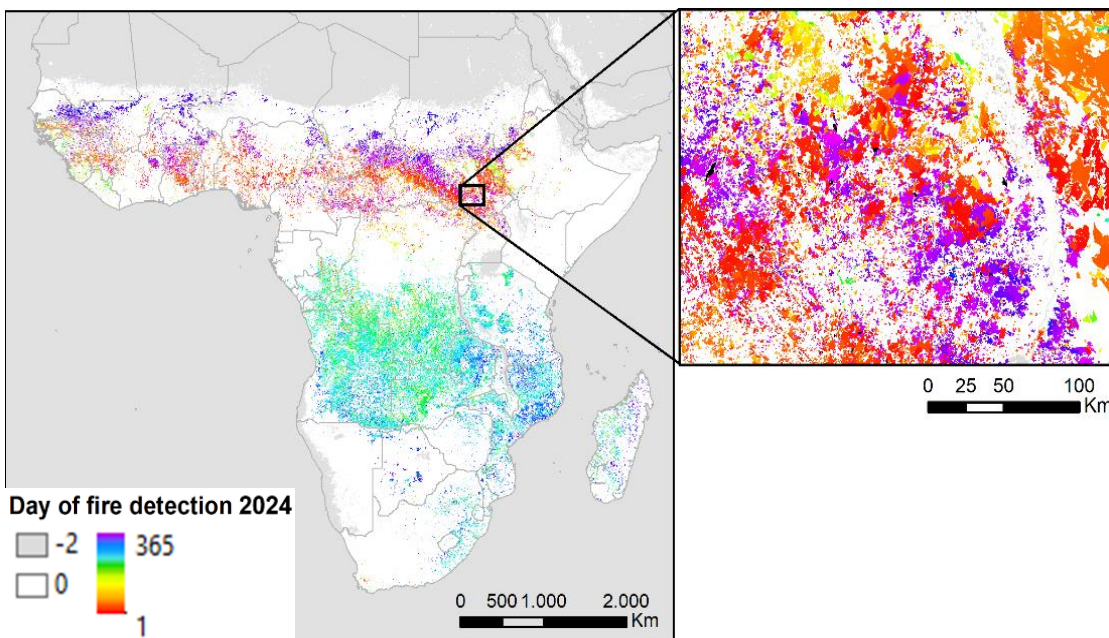
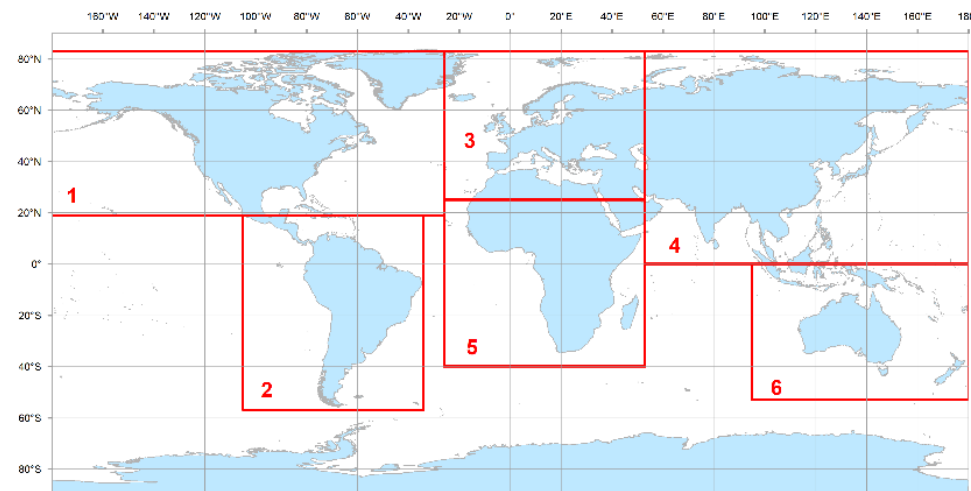


FireCCI medium-resolution global dataset



Pixel Product:

- Spatial resolution: 0.00277778 degrees (approximately 300 m at the Equator)
- 6 continental tiles.
- 3 layers: Julian day of detection (JD), confidence level (CL) and land cover (LC).
- GeoTIFF format.

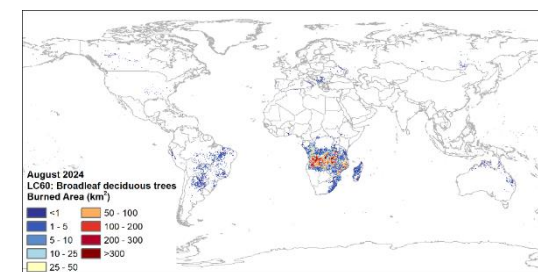
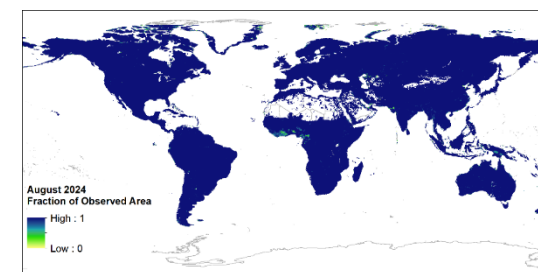
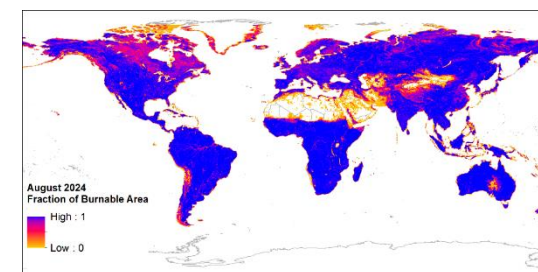
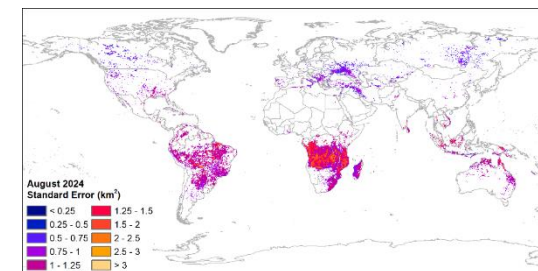
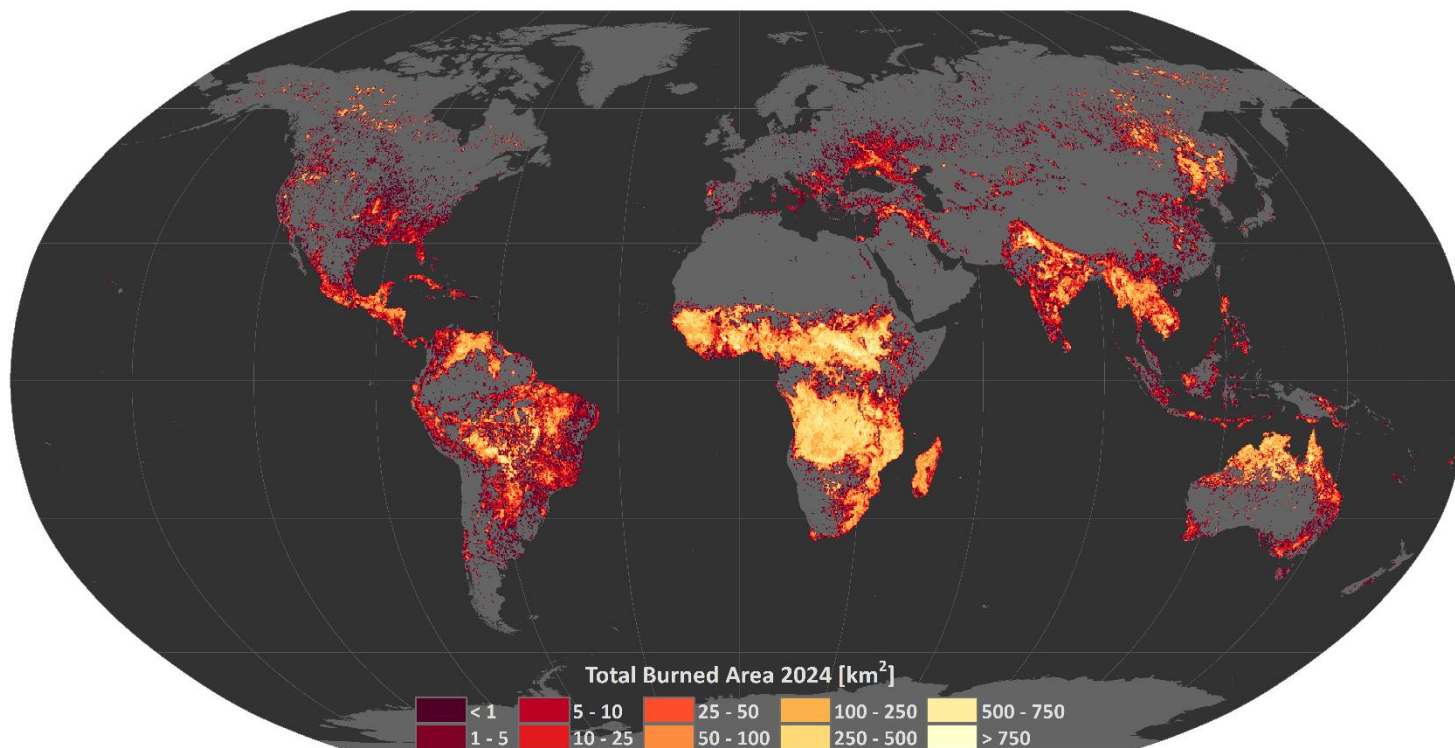


FireCCI medium-resolution global dataset

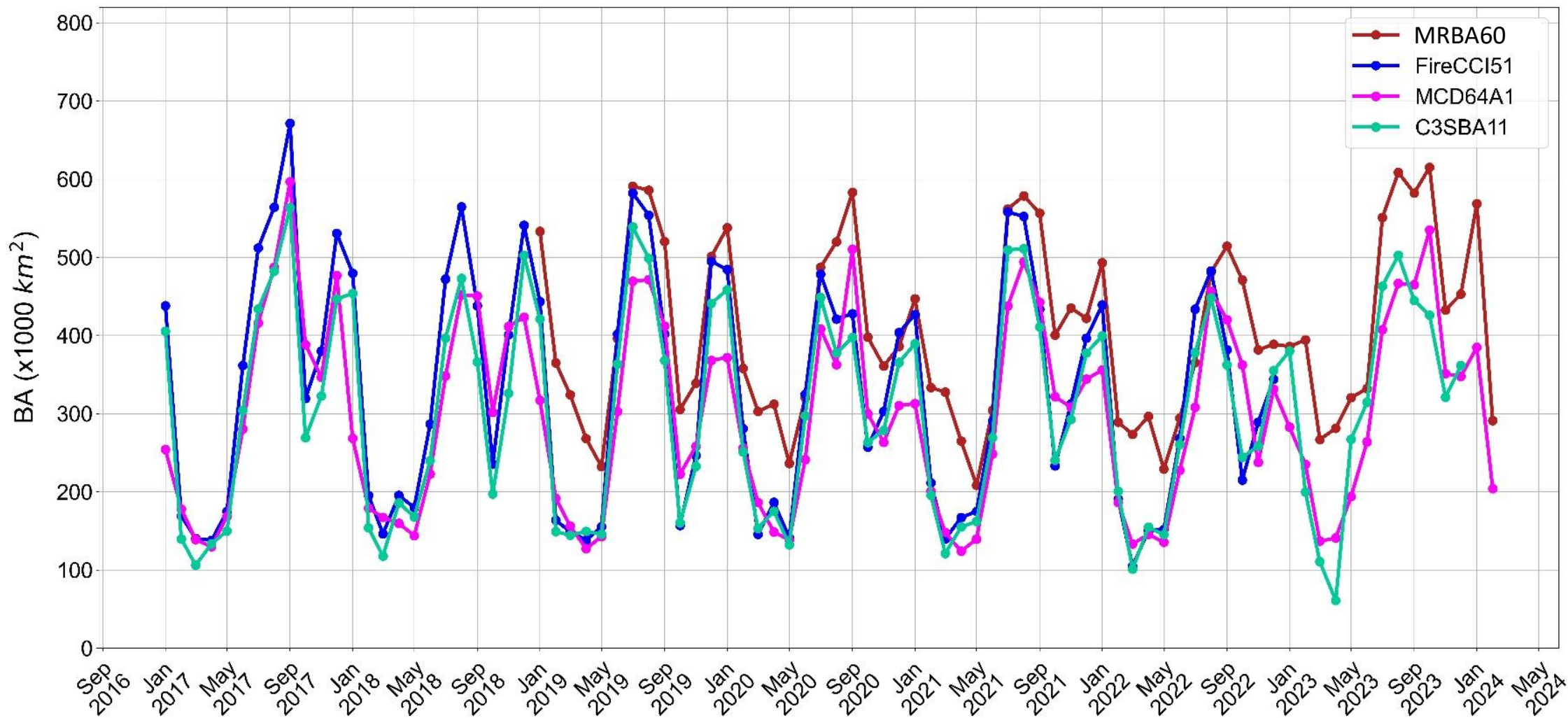


Grid Product:

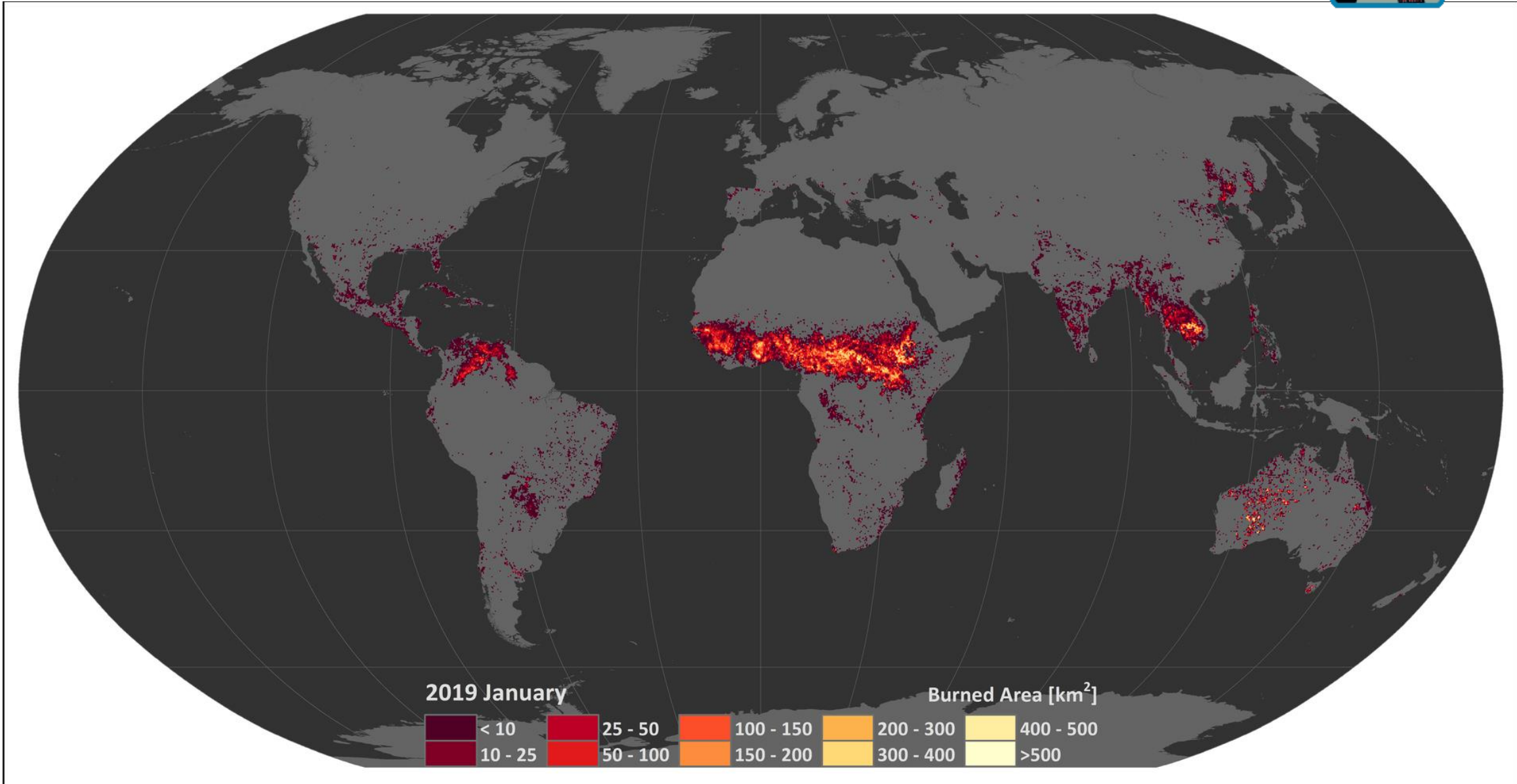
- Spatial resolution: 0.25 deg
- 1 global file.
- 22 layers: sum of BA, standard error, fraction of burnable area, fraction of observed area, and BA per land cover.
- NetCDF format.



FireCCI medium-resolution global dataset



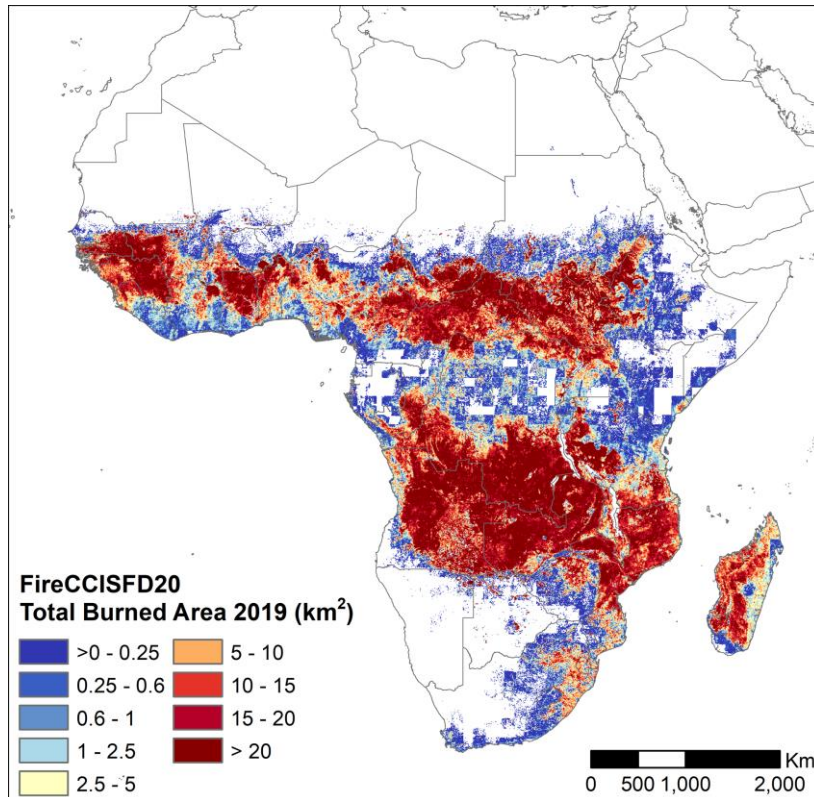
FireCCI medium-resolution global dataset



FireCCI high-resolution datasets

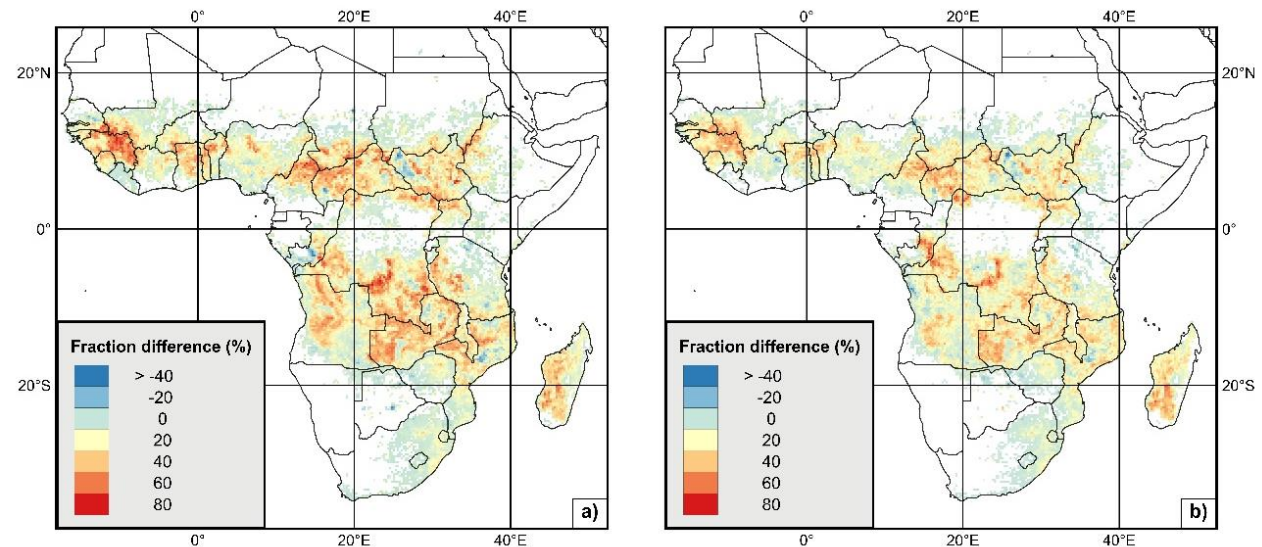


- **FireCCISFD11**: 2016. Based on Sentinel-2 A and MODIS AF.
- **FireCCISFD20**: 2019. Based on Sentinel-2 A&B and VIIRS AF.



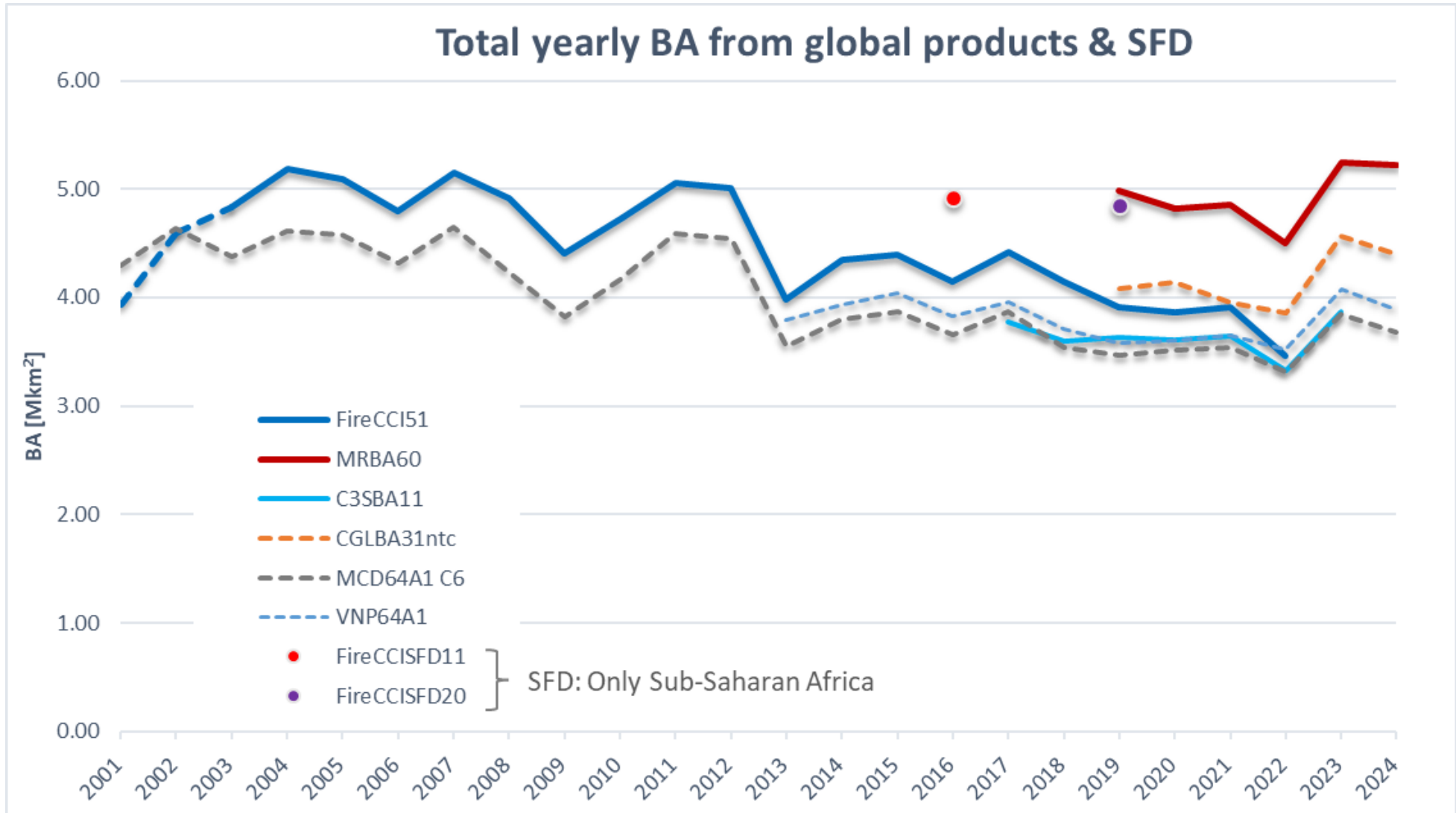
Chuvieco et al. (2022), DOI: 10.1016/j.scitotenv.2022.157139

- 4.8 Mkm² just for Africa. More BA in all months.
- 80% more BA than FireCCI51 (MODIS 250 m)
- 120% more BA than MCD64A1 (MODIS 500 m)



Difference in BA proportion between FireCCISFD20 and a) MCD64A1 and b) FireCCI51

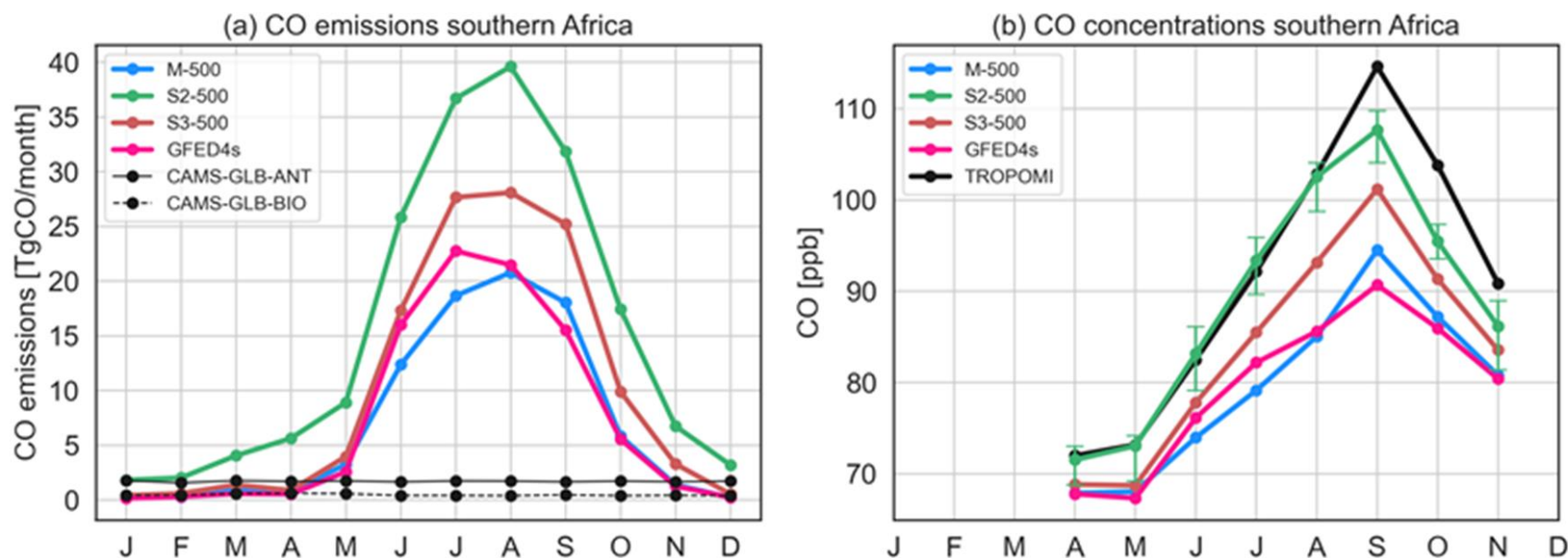
Global / SFD annual burned area



FireCCI high-resolution datasets

Impact for Climate Modelling:

- BA datasets based on Sentinel-2 data show much more BA than medium-resolution products.
- Emissions data estimated from these products are closer to observations.

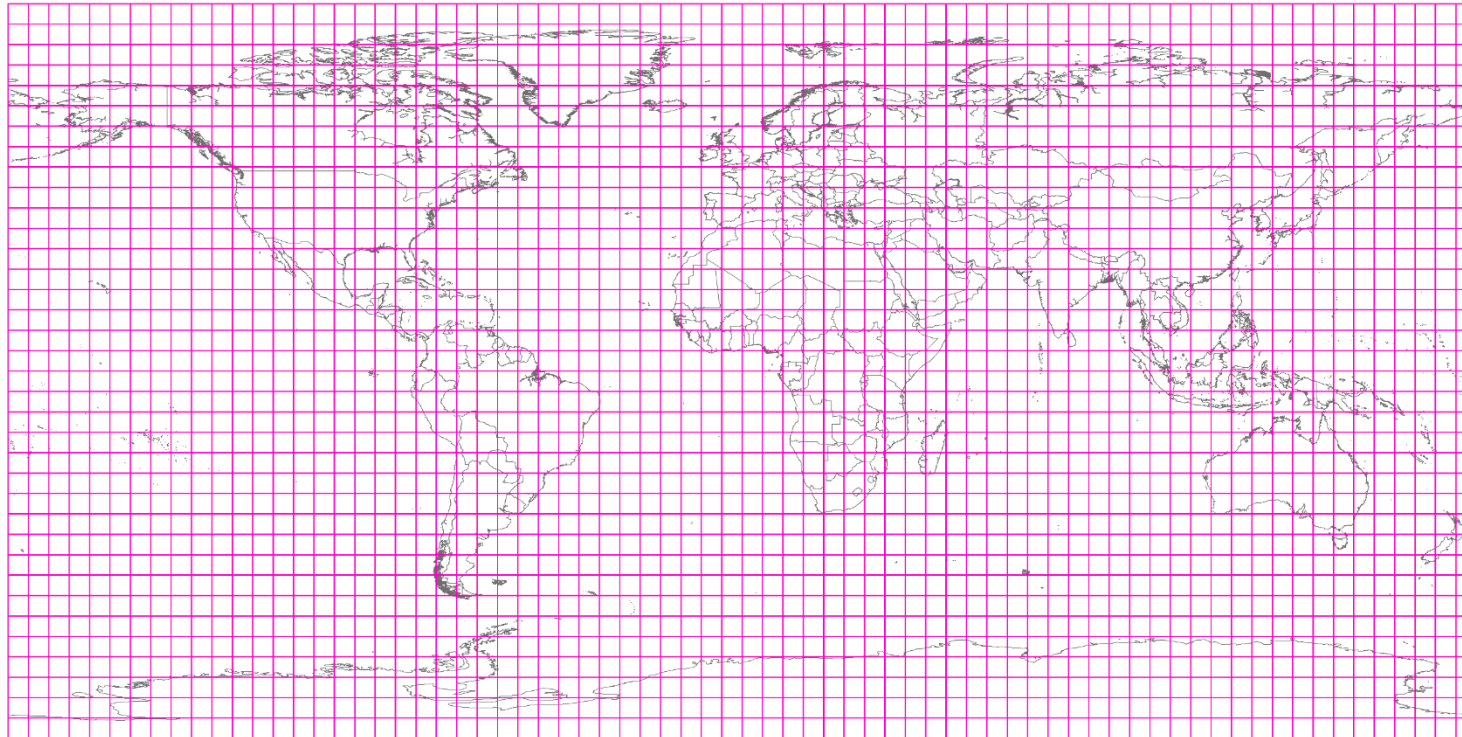


M-500: emissions derived from MCD64A1C6. S2-500: emissions derived from FireCCISFD20. S3-500: emissions derived from FireCCIS311. All BA products resampled to 500m spatial resolution for the analysis.

HRBA10: Sentinel-2 global dataset



- HRBA10: High-resolution Burned Area product v1.0 - 2023
- Inputs: Sentinel-2 A&B MSI surface reflectance + VIIRS active fires.
- Algorithm: Similar to FireCCISFD20. 2 phases: seeding using AFs + patch growing using NBR2 and MIRBI indices.
- **Pixel product:** monthly 5x5-deg tiles at 20m spatial resolution.



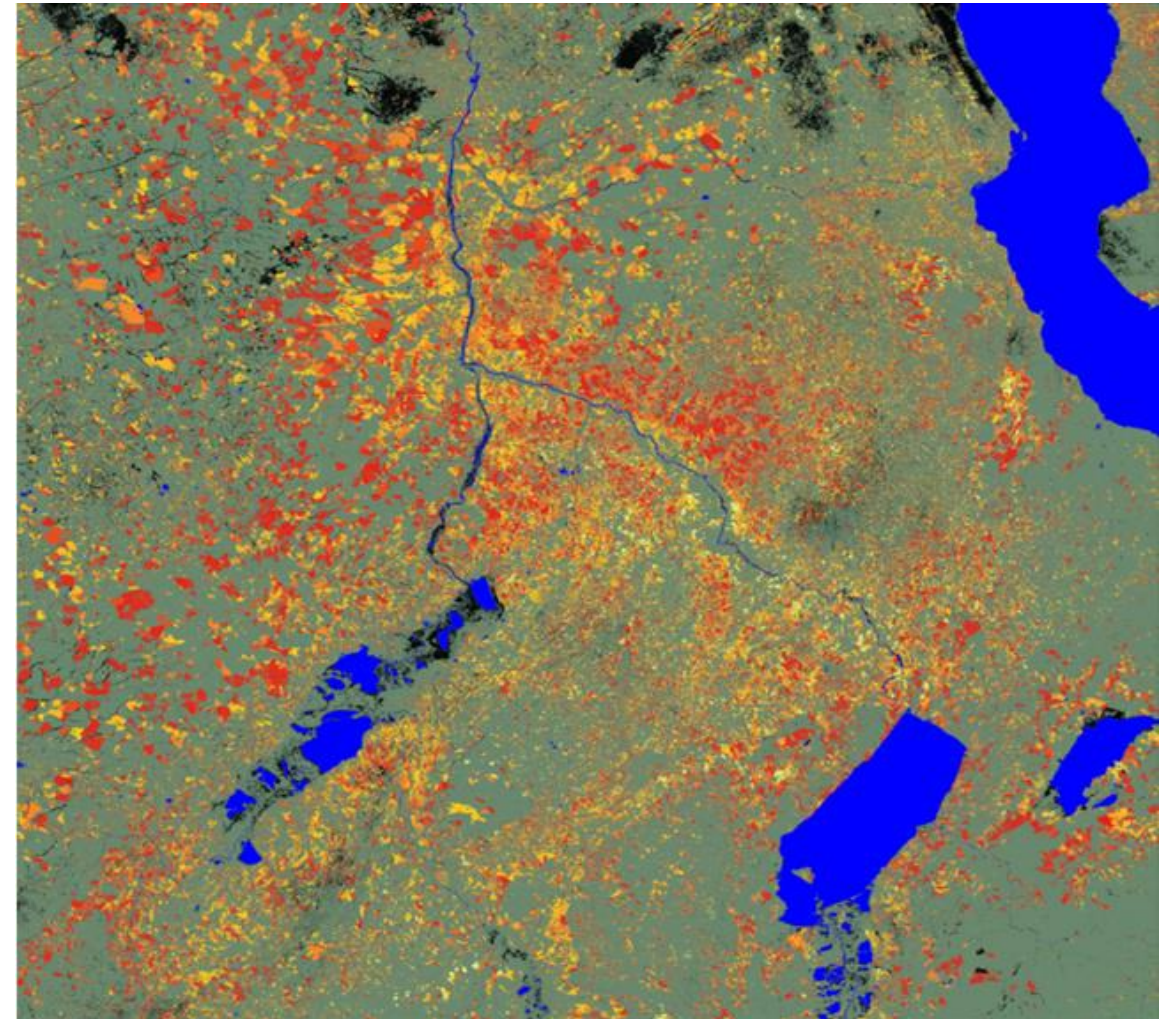
HRBA10: Sentinel-2 global dataset



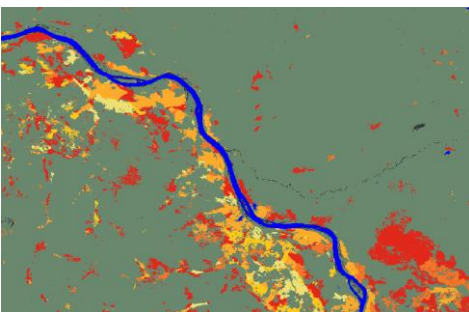
Layers:

- Julian Day of detection
 - Confidence Level
 - Land cover burned (from WorldCover v2 dataset)
-
- Example of 1 of 1171 land tiles:

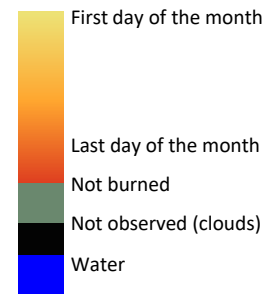
Monthly Images



Detail



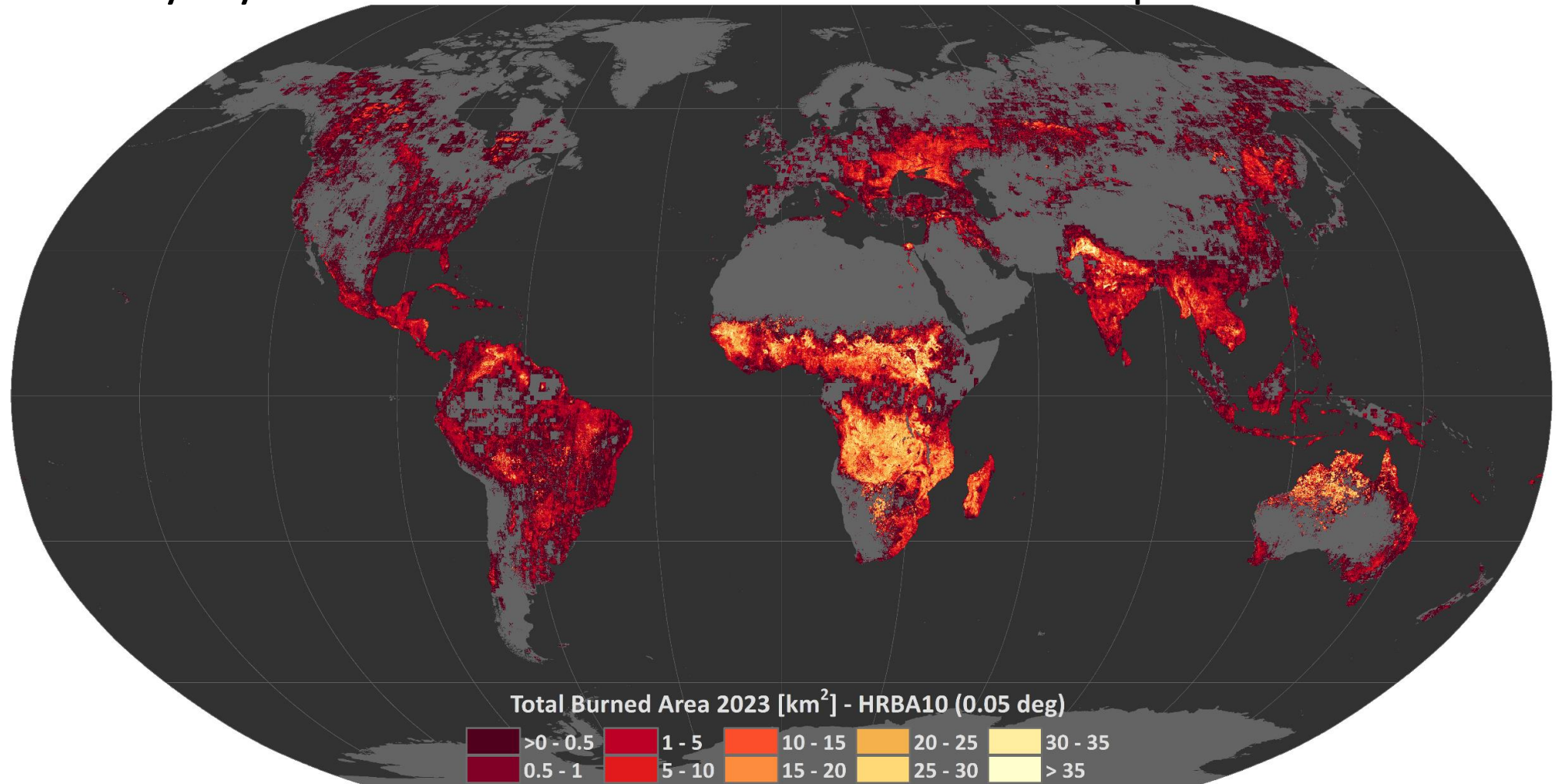
Day of Burn



HRBA10: Sentinel-2 global dataset



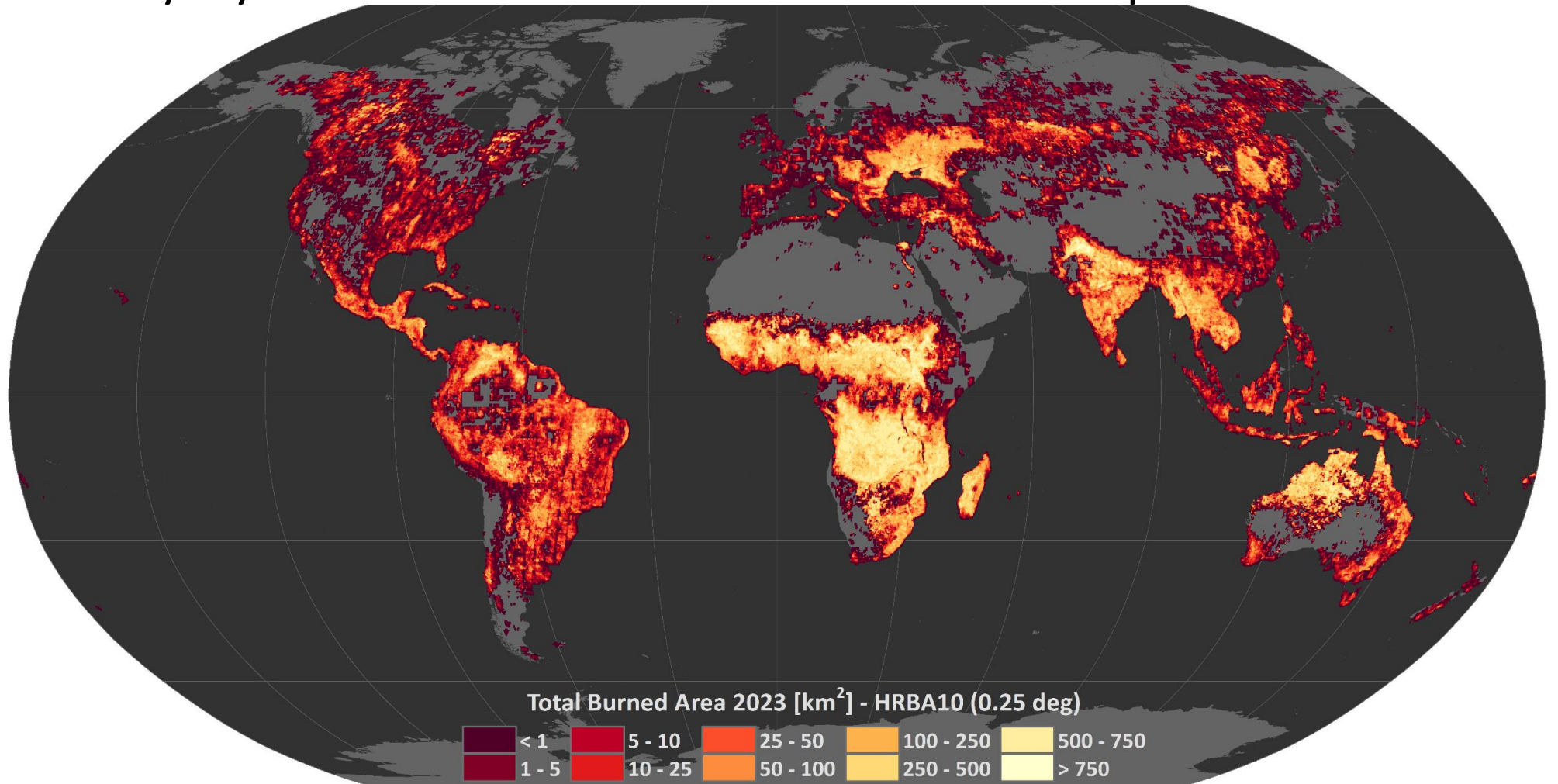
- **Grid product:** global 0.05-deg NetCDF files.
- All ancillary layers as in the case of medium-resolution products.



HRBA10: Sentinel-2 global dataset



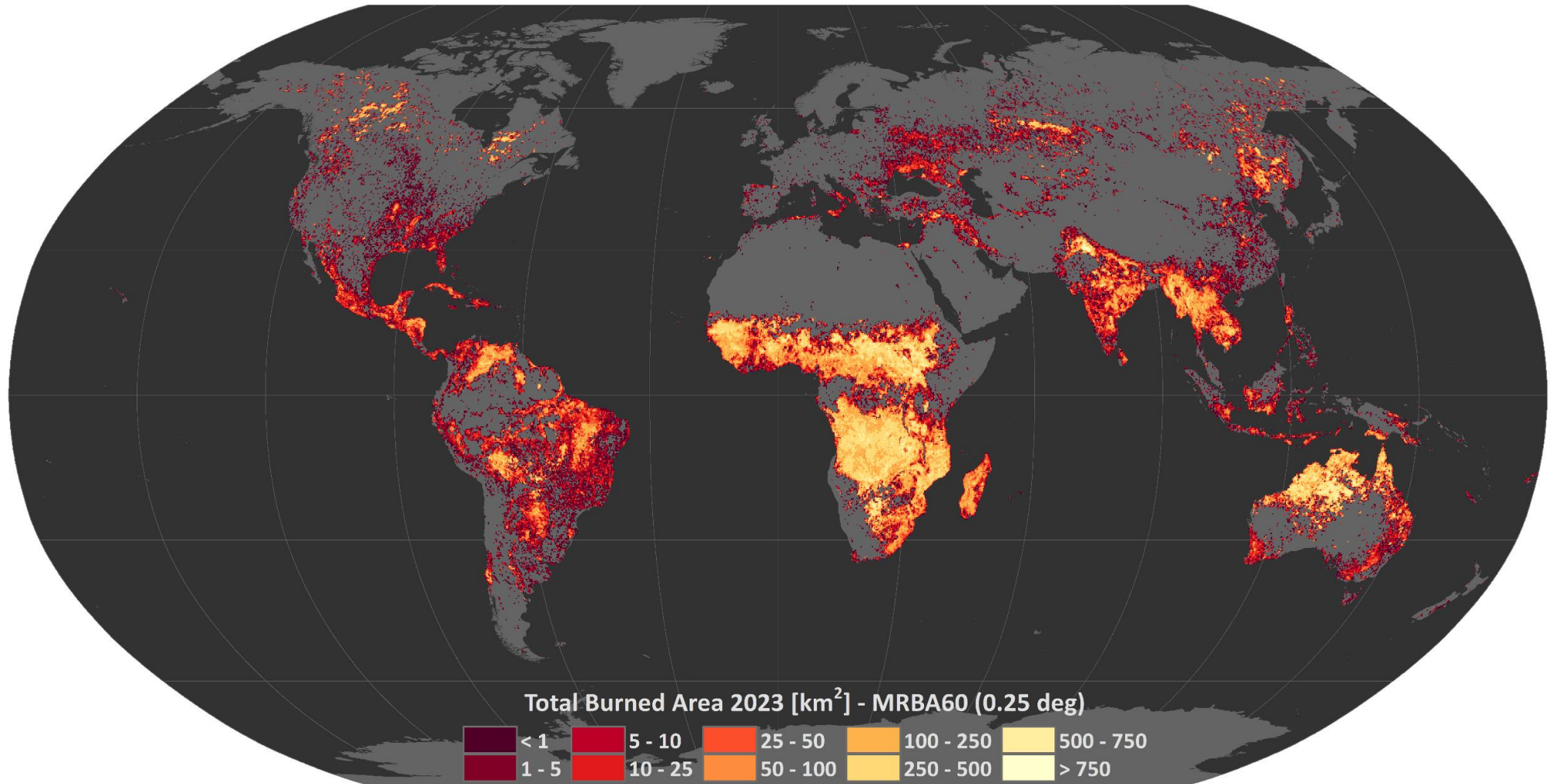
- **Grid product:** global 0.05-deg NetCDF files.
- All ancillary layers as in the case of medium-resolution products.



HRBA10: Sentinel-2 global dataset



- Compared to the MRBA60 medium-resolution dataset:



HRBA10: Sentinel-2 global dataset



- **Grid product:** global 0.05-deg NetCDF files.



HRBA10: Sentinel-2 global dataset

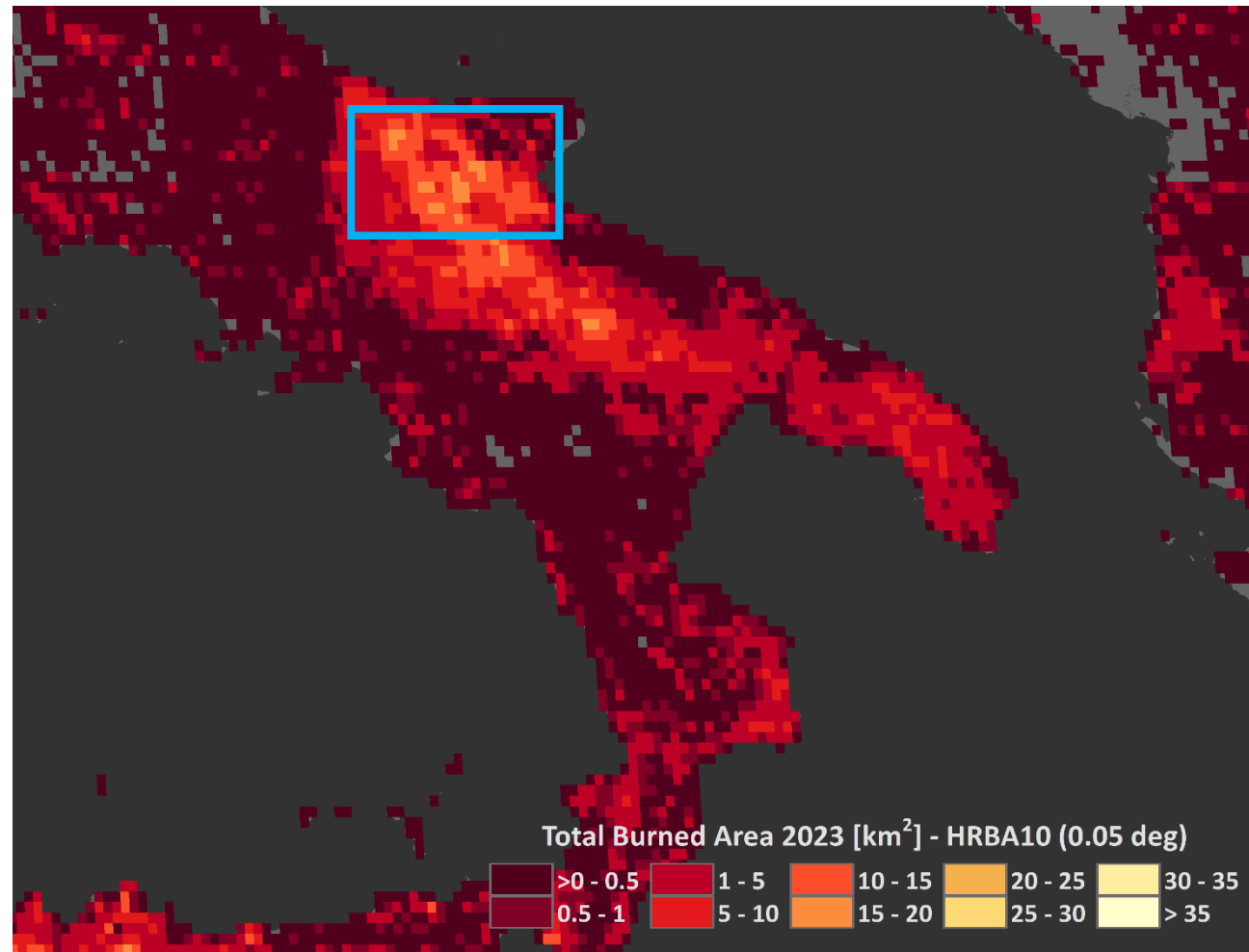
Grid product: 0.05-degrees



Cropland burning around San Severo (Italy).

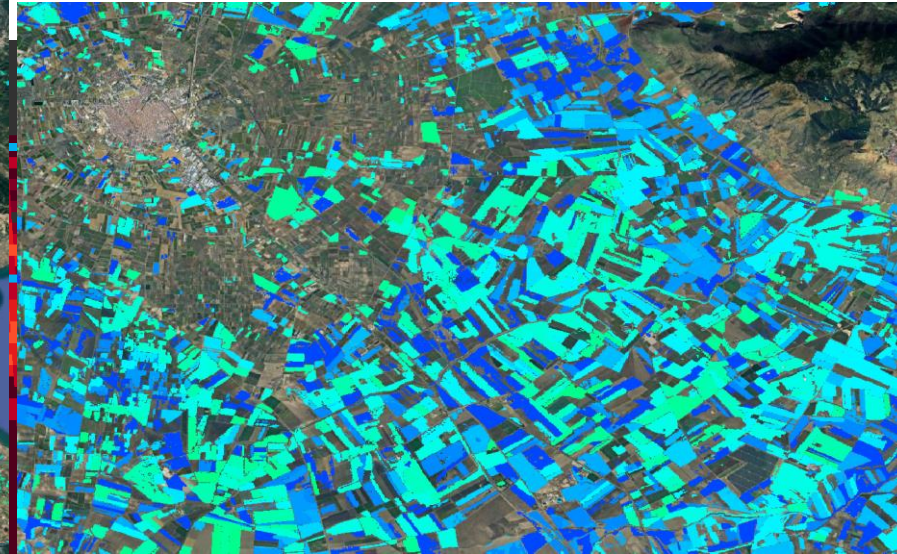
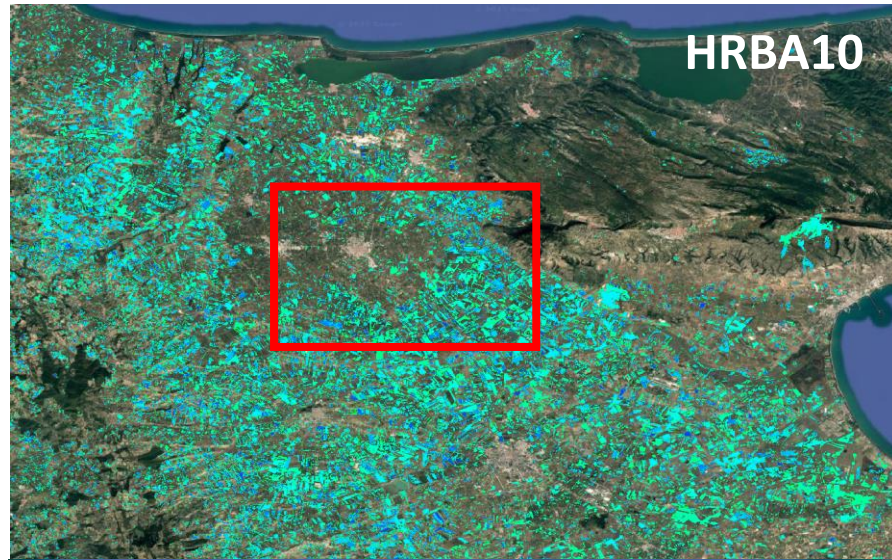
Julian day of detection of the fire, from green (June) to blue (September).

Sentinel-2 image composition (SWIR-NIR-R) of 09 October 2023.



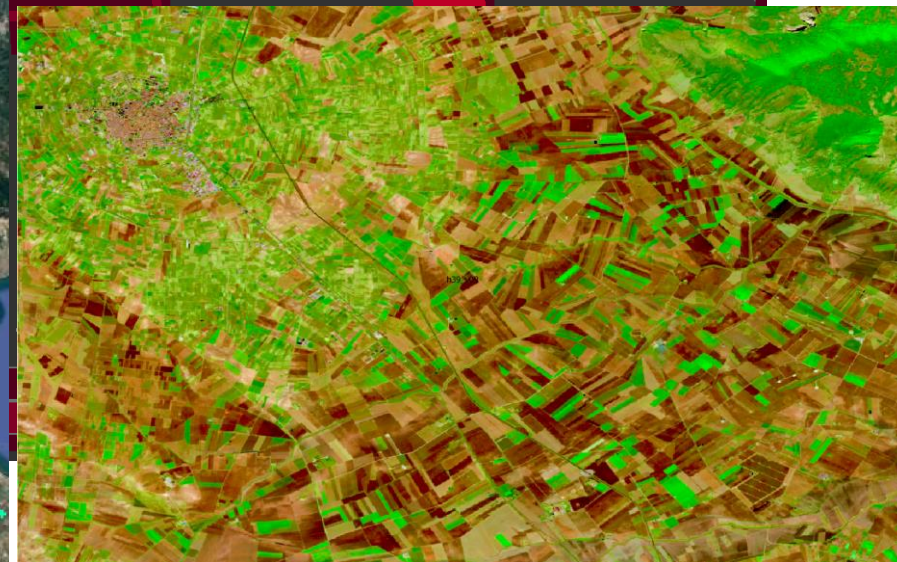
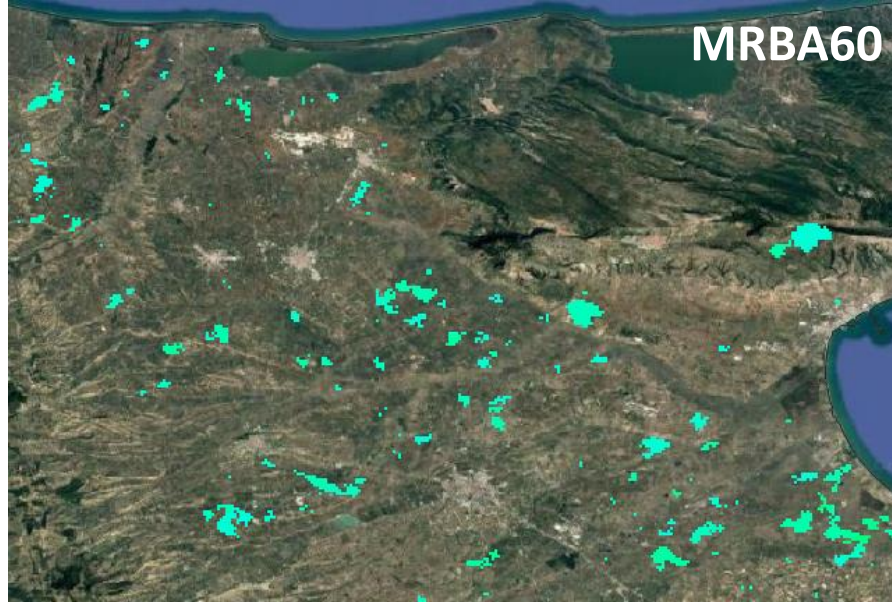
HRBA10: Sentinel-2 global dataset

Pixel product: 20 m spatial resolution



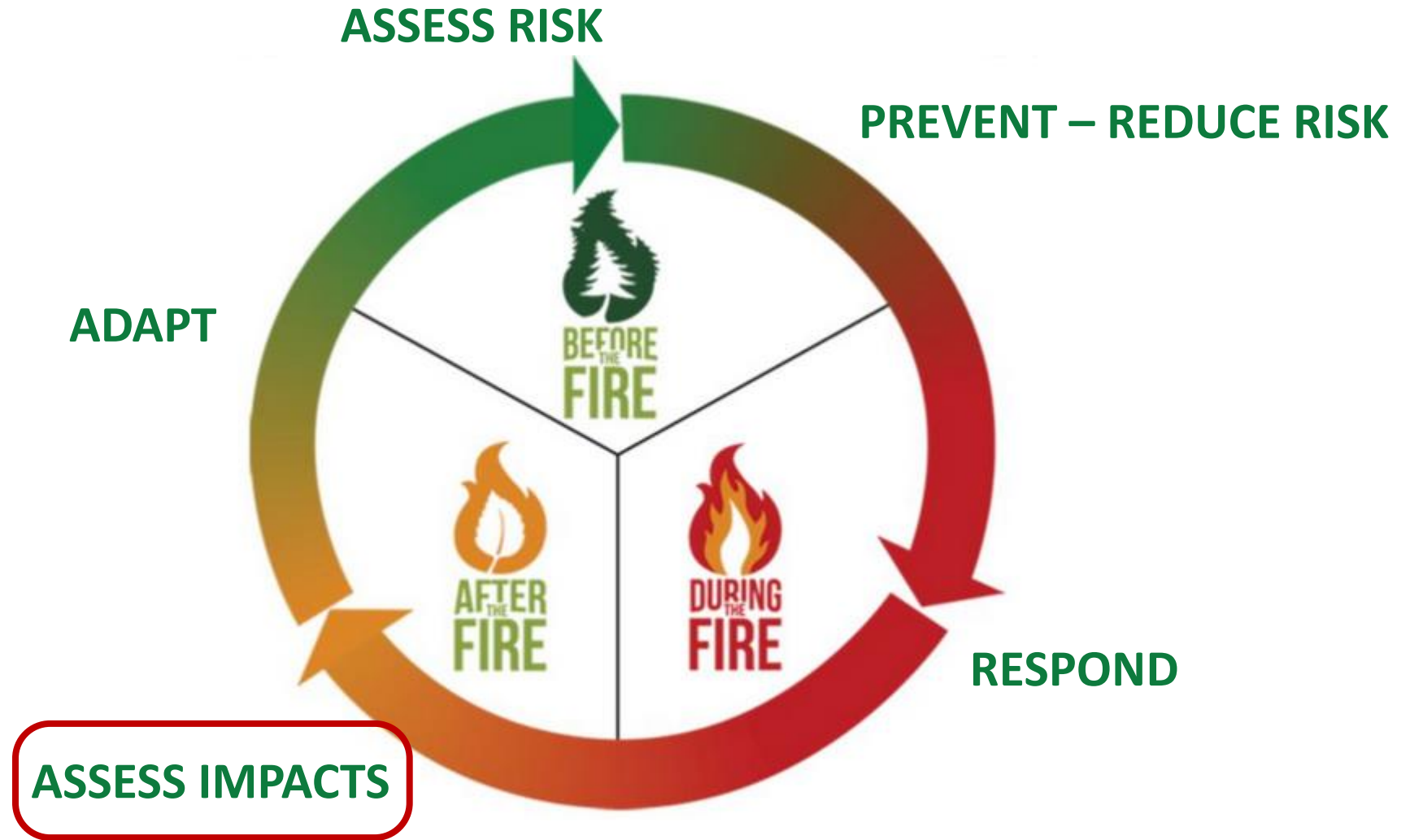
Cropland burning around San Severo (Italy).

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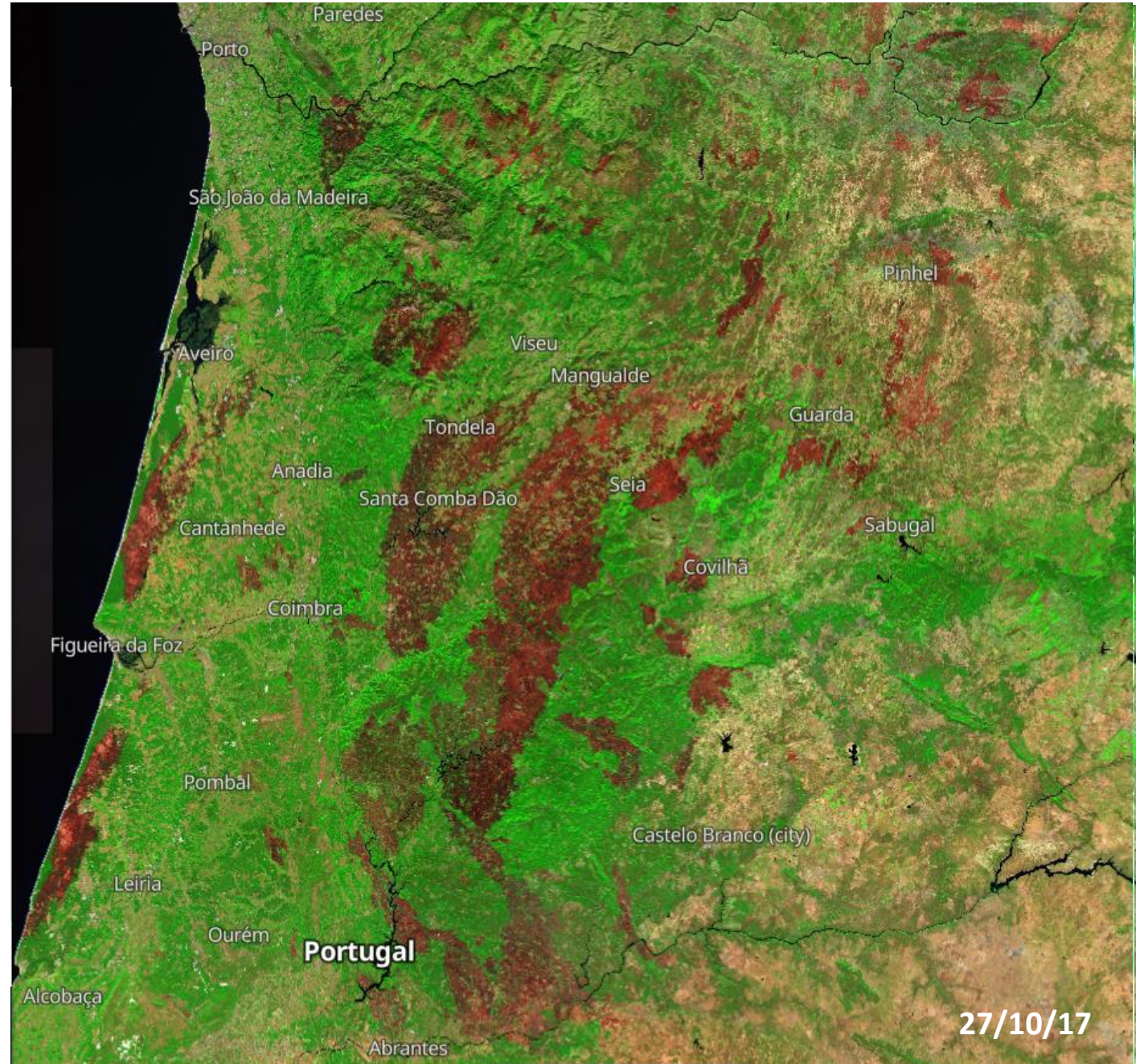
Sentinel-2 image composition (SWIR-NIR-R) of 09 October 2023.

The fire cycle



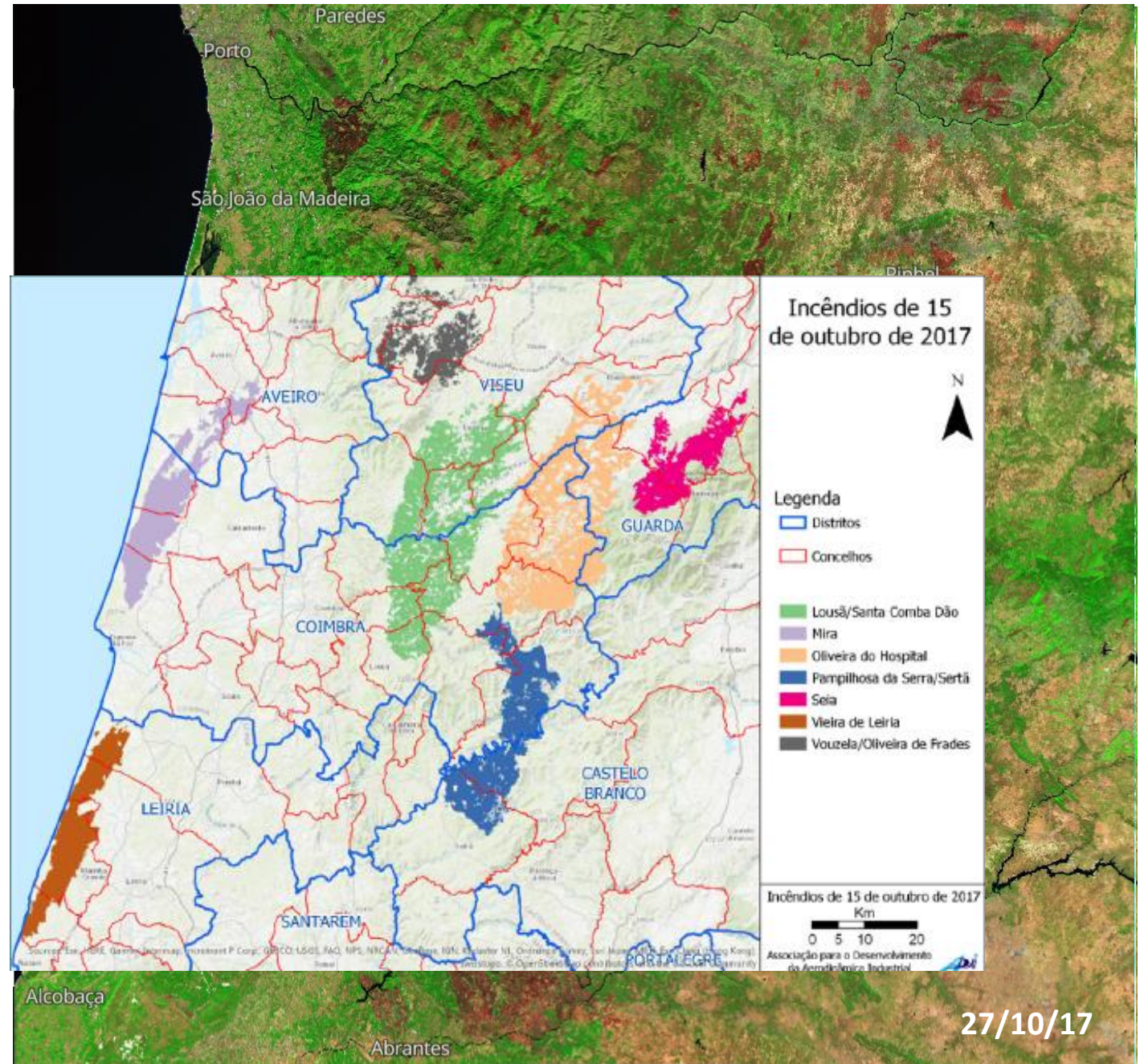
Fire impacts

- **Pedrógao Grande:** 17 - 22/06/2017. BA: 45.328 ha, 66 fatalities. Cause: 25 kV electric line
- 17/06: Severe drought. 40°C.
- **October fires:** 15/10: 500 ignition points. 244.000 ha burned in 10 hours. 51 fatalities.
- Drought conditions + Ophelia hurricane.



Fire impacts

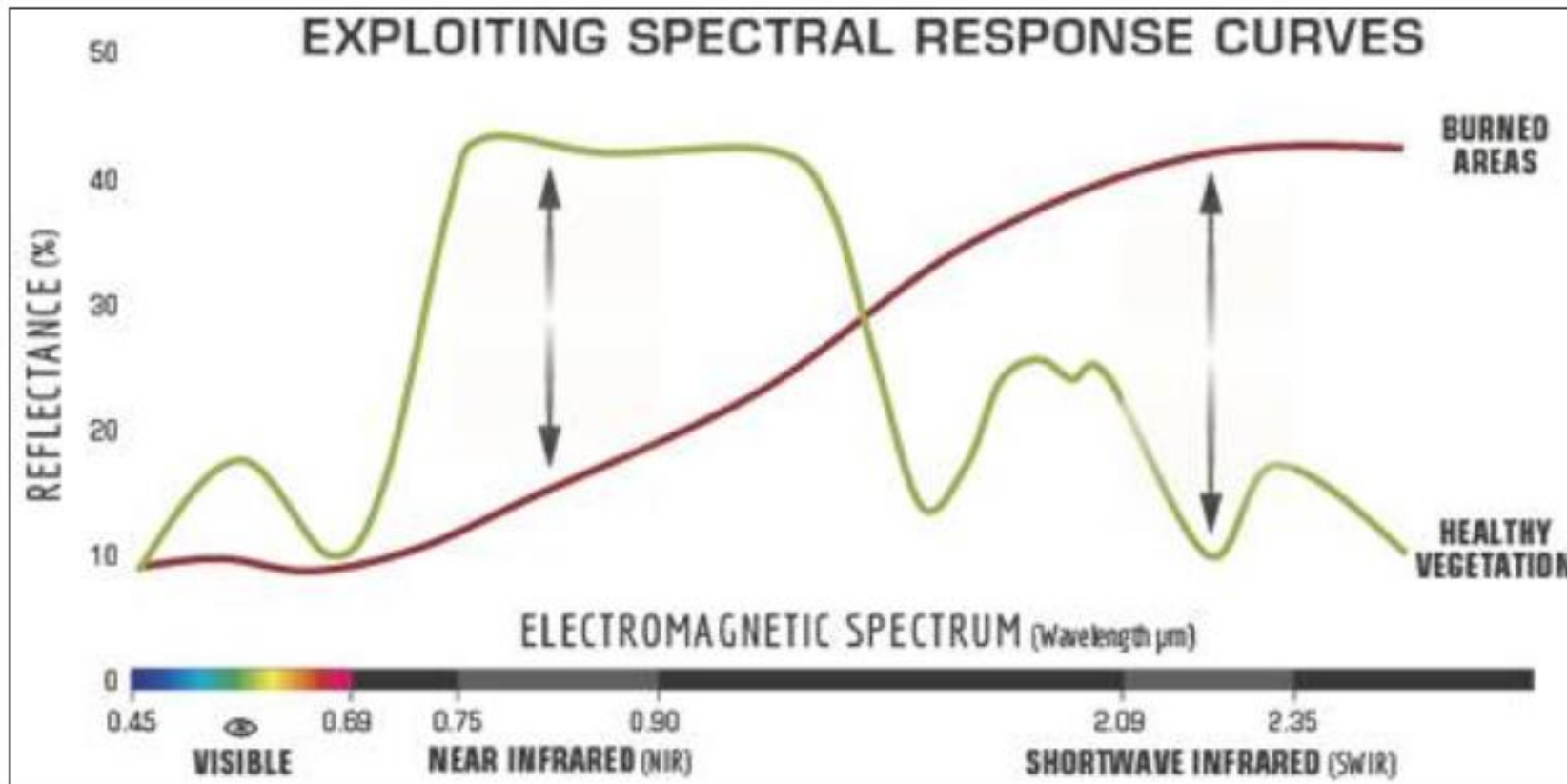
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- Drought conditions + Ophelia hurricane.



27/10/17

Fire impacts: fire severity

NBR - Normalised Burned Ratio: index designed to highlight burned areas. A high value indicates healthy vegetation, and a low value indicates bare soil and recently burned areas.



$$\text{NBR} = \frac{\text{NIR} - \text{SWIR}}{\text{NIR} + \text{SWIR}}$$

Fire impacts: fire severity

dNBR: difference between pre-fire NBR and post-fire NBR – used to estimate fire severity.

A high value of dNBR indicates higher severity, and negative values can indicate vegetation regeneration post fire, or not burned areas.

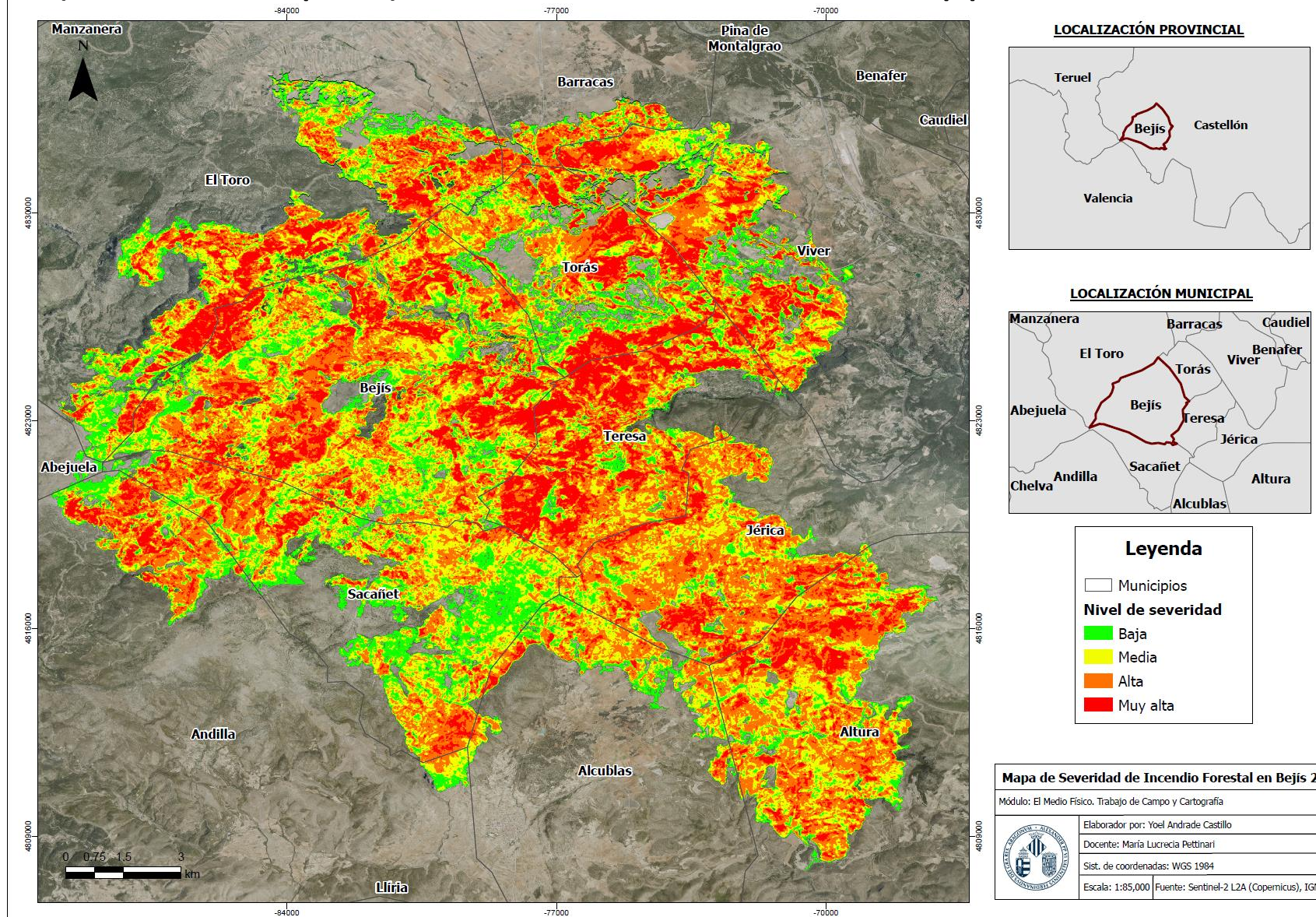
$$\text{dNBR or } \Delta\text{NBR} = \text{PrefireNBR} - \text{PostfireNBR}$$

Table 1. Burn severity levels obtained calculating dNBR, proposed by USGS. Key & Benson (2006)

Severity Level	dNBR Range (scaled by 10^3)	dNBR Range (not scaled)
Enhanced Regrowth, high (post-fire)	-500 to -251	-0.500 to -0.251
Enhanced Regrowth, low (post-fire)	-250 to -101	-0.250 to -0.101
Unburned	-100 to +99	-0.100 to +0.99
Low Severity	+100 to +269	+0.100 to +0.269
Moderate-low Severity	+270 to +439	+0.270 to +0.439
Moderate-high Severity	+440 to +659	+0.440 to +0.659
High Severity	+660 to +1300	+0.660 to +1.300

Fire impacts: fire severity

- **Bejis fire (Castellón, Spain): 15/08 -13/09/2022. BA: approx. 18.550 ha**





Conclusions

- Remote Sensing is a very useful tool for fire research:
 - Pre fire → risk assessment
 - During – After fire → fire location and burned area detection
 - After fire → analysis of fire impacts (vegetation loss, emissions, health impacts) and help with restoration efforts
- Burned area mapping has a long history of algorithms and products → new algorithms and better sensors are improving our capacity to detect the “true” reality of fire occurrence.
- Still room for improvement → algorithm refinement, high resolution datasets → processing challenges.

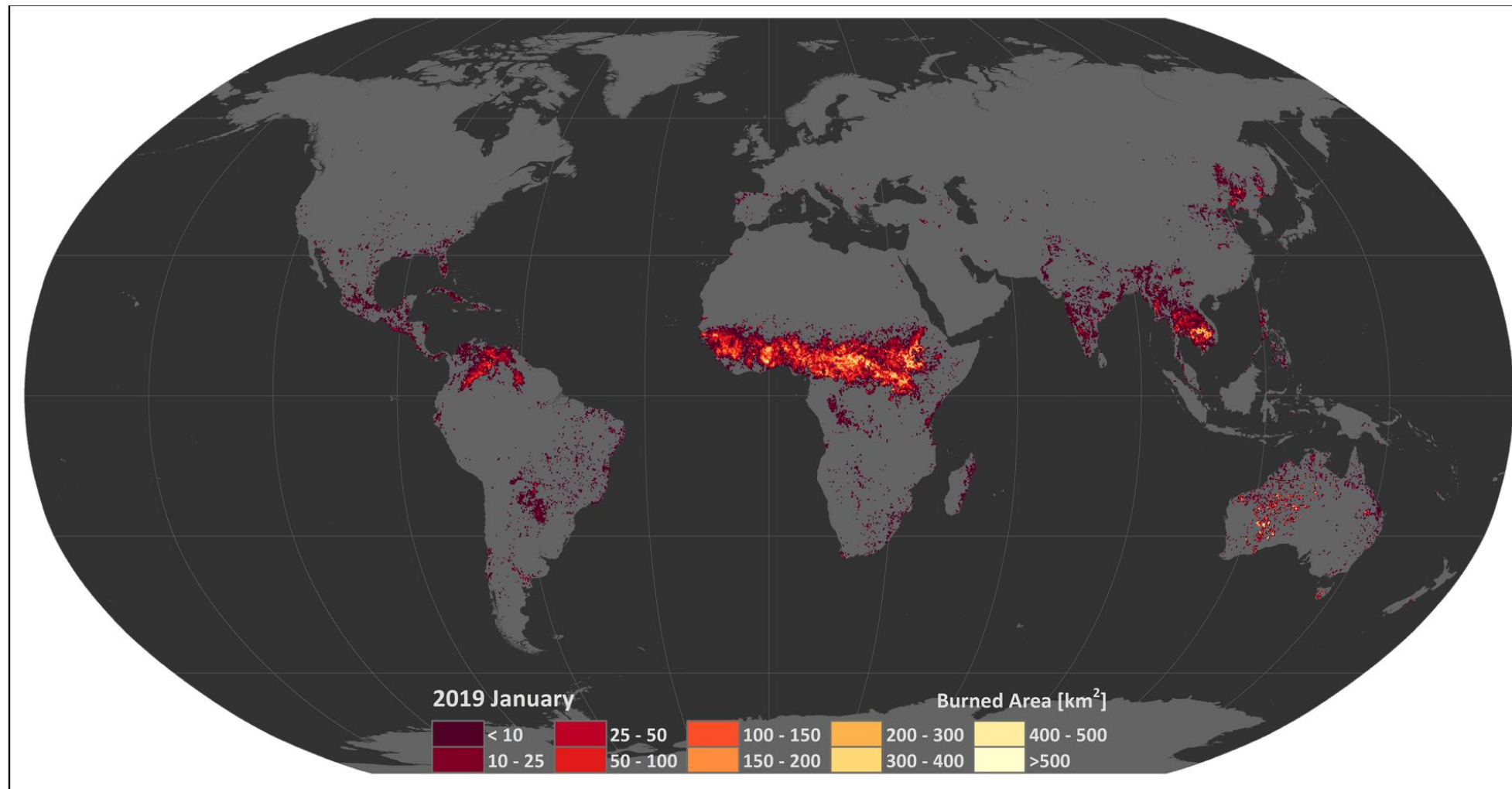


fire
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<https://climate.esa.int/en/projects/fire/>