A wide view over Remote Sensing for Fire Mapping

Dr. Veronica Andreo

Department of Earth Observation Sciences,
Faculty of Geo-Information Science and Earth Observation
University of Twente

Workshop On Stochastic Mapping Of Bushfires

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How do we see fire from space?

Wildfire in Pilliga National Park, New South Wales, Australia. Jan 18, 2018.

Copernicus Sentinel 2B - True color composition and SWIR band.
Source: Sentinel-hub EO browser

Presentation Overview

1. Basics of RS for fire detection and mapping
2. Remote sensing of active fires (AF)
3. Remote sensing of burned areas (BA)
4. Spectral indices and burn severity
5. Online monitoring and forecast systems
6. Latest developments in burned area mapping

Remote sensing for fire detection and mapping

Fire is a disturbance factor and an agent of environmental change with local to regional impacts on land use, productivity, carrying capacity and biodiversity, and regional to global impacts on hydrological, biogeochemical and atmospheric processes.

Space-borne sensors provide a unique perspective to monitor and study the global distribution and characteristics of fire. Data from RS have been used to:

- monitor smoke plumes,
- monitor flaming and smouldering fire locations and timing,
- monitor/estimate the extent of fire-affected areas,
- characterize various fire properties.

Pilliga Fire - Jan 2018

Center of operations - Jan 2018

Remote sensing for fire detection and mapping

In the early days…

- satellite fire maps were obtained by **visual photo-interpretation** techniques (highly time consuming and expensive)

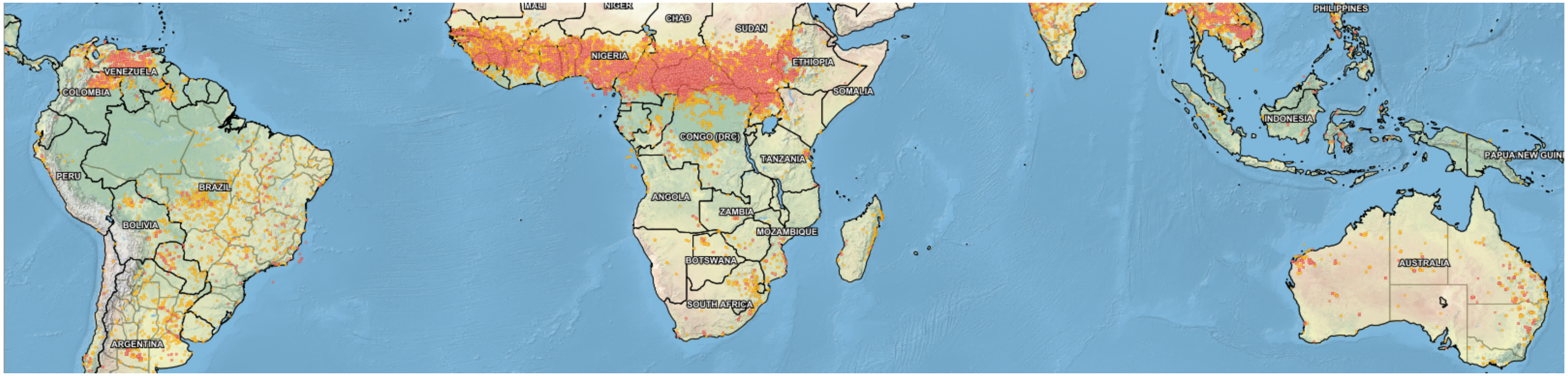
Nowadays…

- satellite fire maps are more usually generated **automatically** (through science algorithms and digital image processing software)
- users of satellite fire information (resource managers, scientists and policy makers) increasingly expect systematically generated, well-characterized satellite fire products to be available **online**

Remote sensing for fire detection and mapping

Only **cost-effective source of information** for mapping AF and BA from **regional/national up to global** scale.

Only source of information for large area/global studies, for multi-temporal analyses and for **areas where ground data are lacking or are not publicly available**.

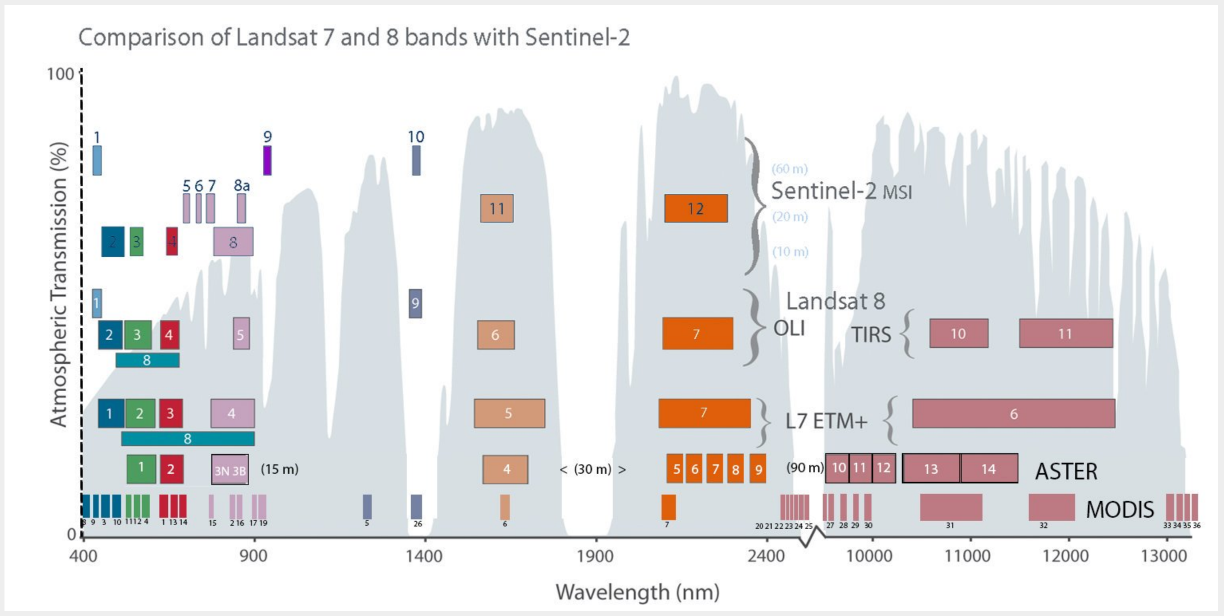


Active fires Near Real Time - MODIS Terra & Aqua

Remote sensing for fire detection and mapping

What does a sensor need to detect fire and map burned areas?

- It should measure reflected or emitted electromagnetic radiation at certain wavelengths, especially **MIR/TIR (for AF detection) and NIR + SWIR (for BA mapping)**
- It should have **short revisit time and (moderate/high) spatial resolution**



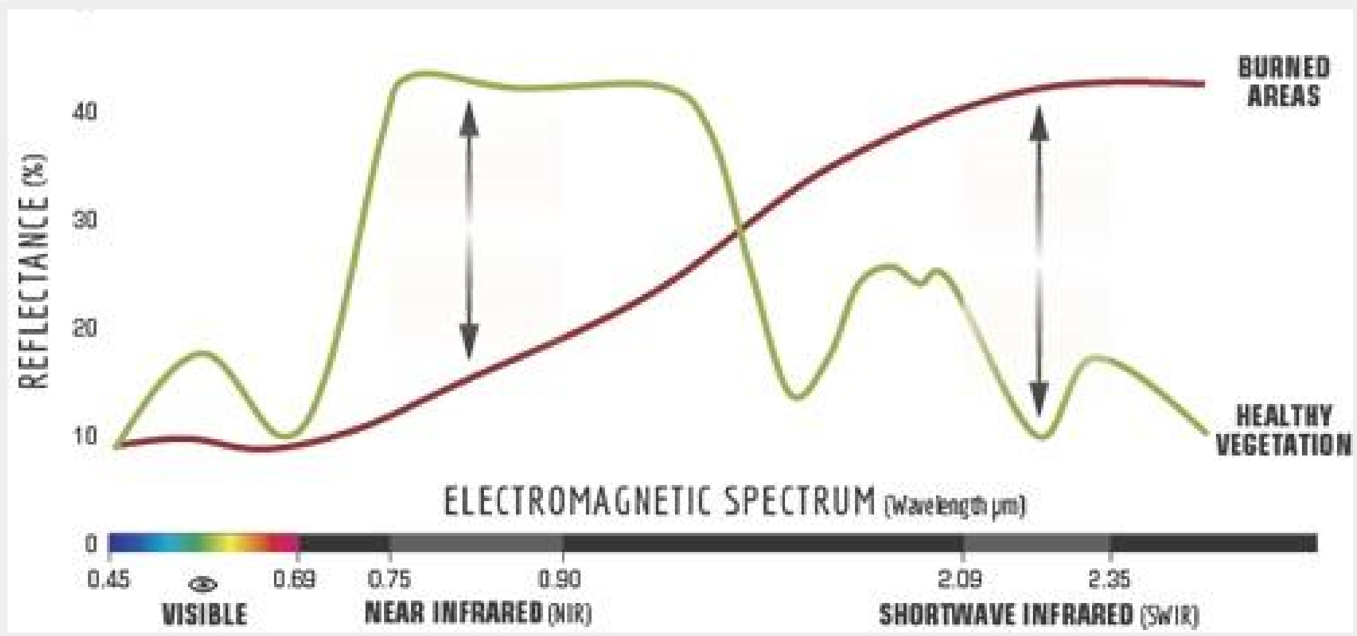
Remote sensing for fire detection and mapping

2 main approaches:

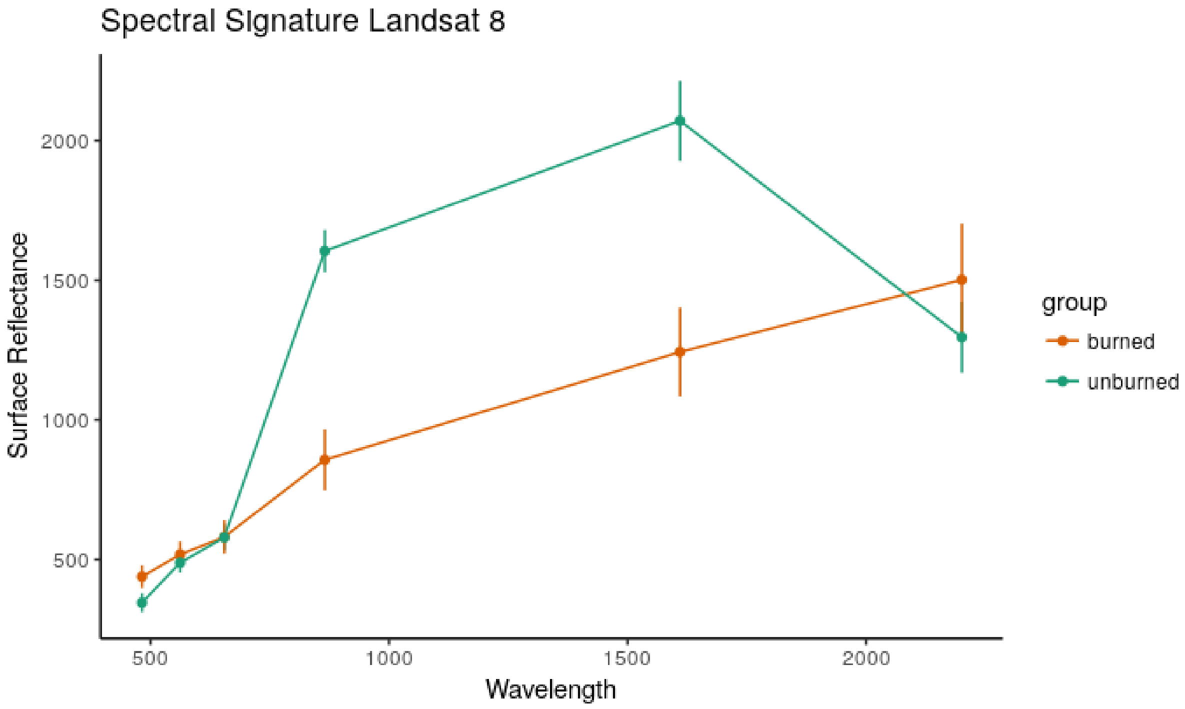
- **thermal contrast** of active fires with regards to the surrounding background
- **reflectance changes** caused by burning effects (changing of leaf and soil colour, leaf losses, char background, ash, etc.)

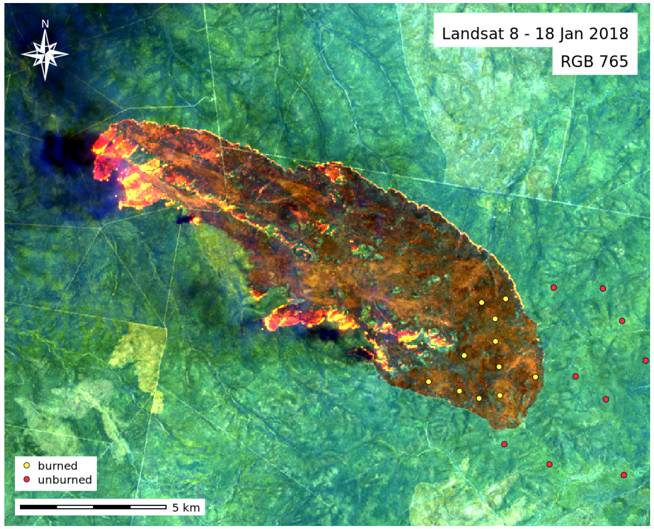
Hybrid approach

Spectral signatures of burned vs unburned areas

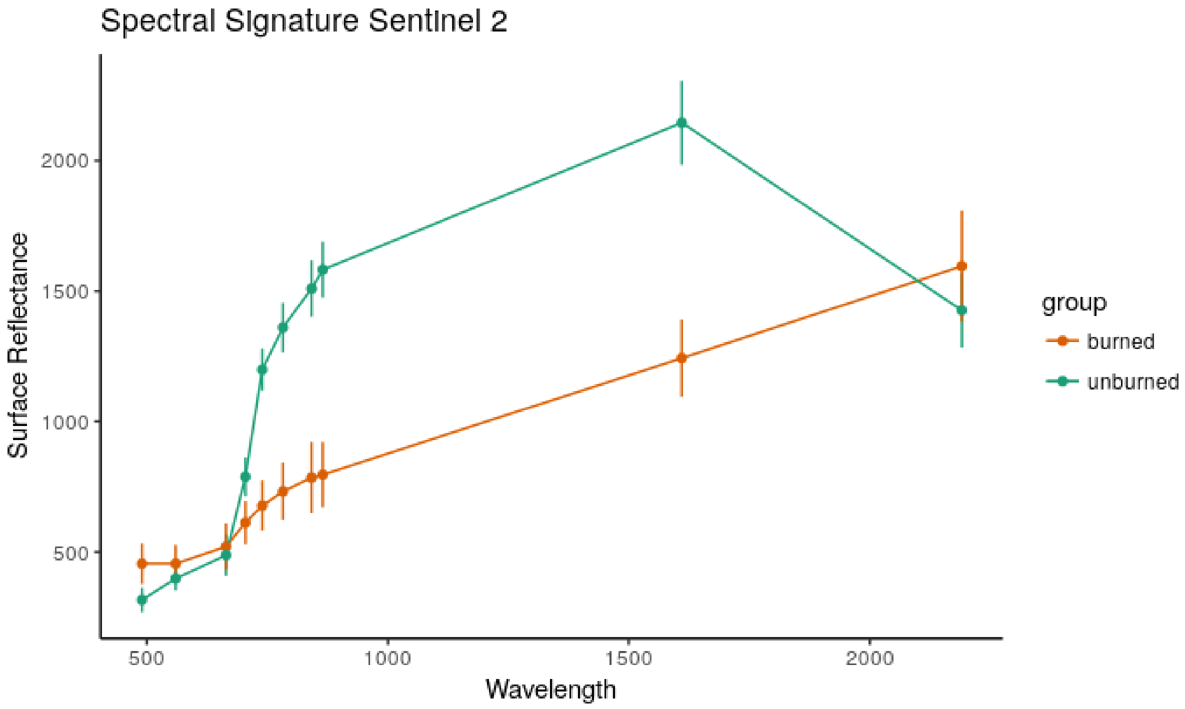


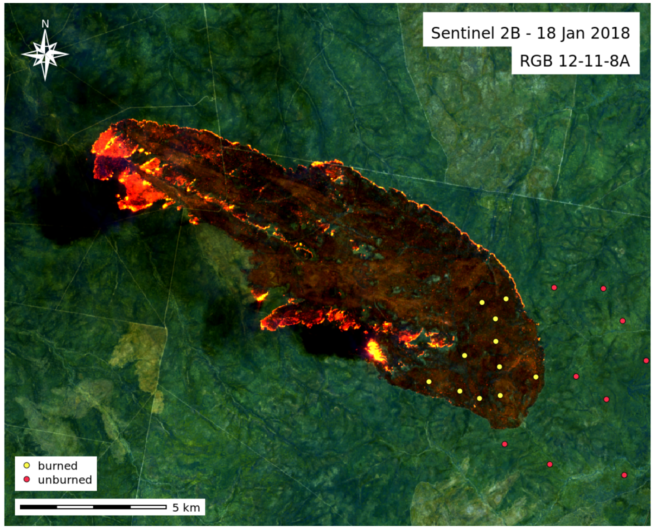
Spectral signatures of burned vs unburned areas



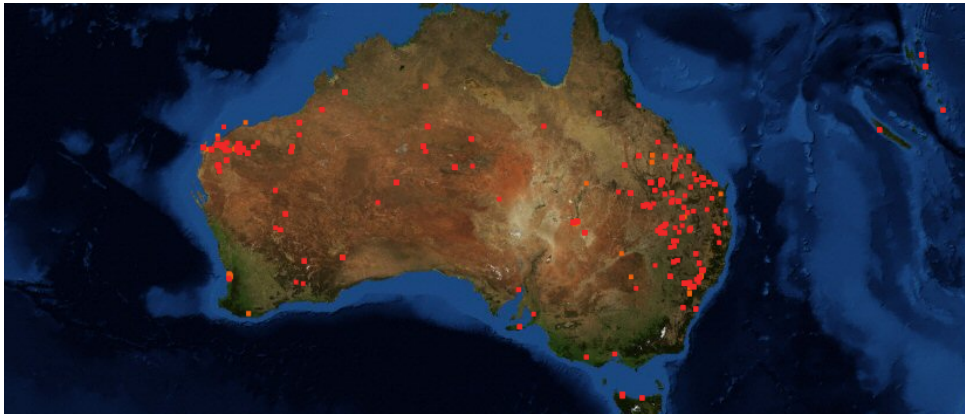


Spectral signatures of burned vs unburned areas





Active Fires



- AF are rather easily **detected with MIR and TIR** bands (evident in the VIS if fire size is large and energy is high)
- The information about AF, i.e. **location, date and time**, is basic for numerous applications including *fire management, fire suppression and early warning* for fires in the vicinity of critical infrastructures
- AF detections from polar-orbiting satellites **undersample the temporal dynamics** of fire (satellite overpass time and clouds) and the **spatial extent** of BA where the fire progresses rapidly across the landscape

Active Fires

Satellites used for AF detection

- NOAA - AVHRR
- NOAA - GOES
- METEOSAT
- VIRS - TRMM
- ATSR
- MODIS - Terra & Aqua
- VIIRS - Suomi NPP

Active Fires

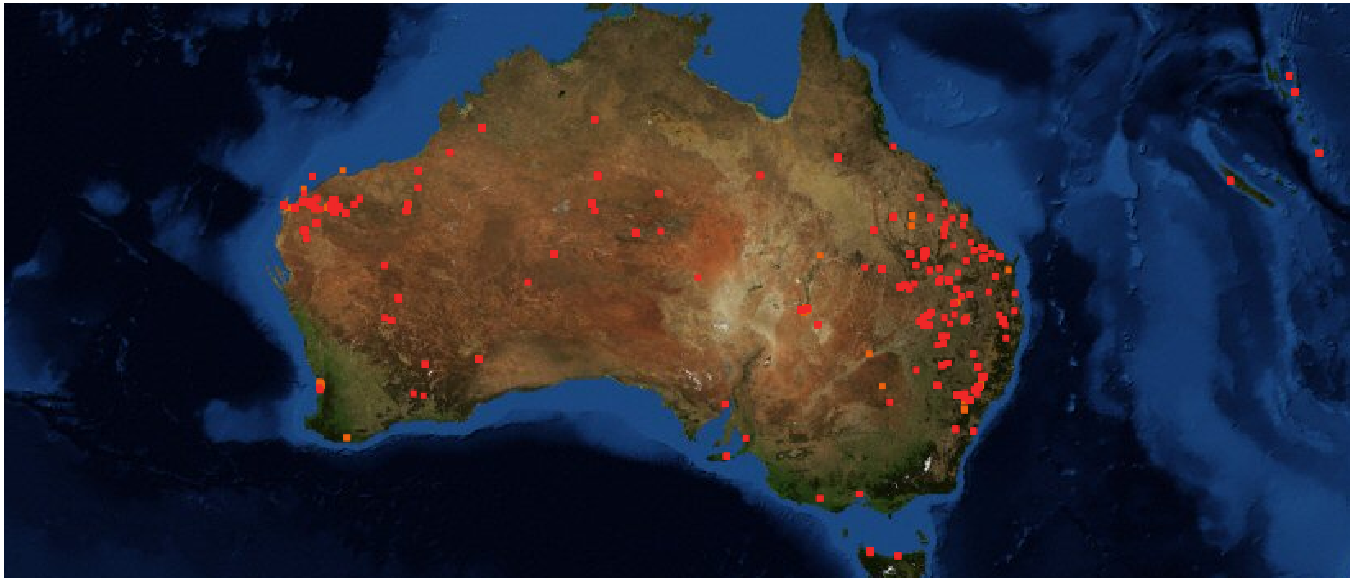
Algorithms for AF detection

- Simple:
  - **Empirical thresholds** based on MIR or TIR bands (day and/or night satellite overpasses)
- More complex:
  - **Contextual algorithms** that use thresholds in MIR/TIR bands and rejection of false positives according to bright temperature of neighbour pixels (MODIS AF product)
  - Provide more reliable and consistent AF monitoring

Active Fires

Operative products

- **MODIS:** MCD14ML (1000 m, daily, 2001-present, Day & Night)
- **VIIRS:** VNP14IMGTDL_NRT (375 m, daily, 2012-present, Day & Night)
- **AVHRR:** FIMMA (1100 m, daily, only USA)



Burned Area

- Support for numerous research and operational applications in resource management, environmental assessment and post-fire remediation.
- Used to estimate gas emissions, needed for climate models and projections of climate change.

Fires produce **black char and ashes** (complete combustion)

Changes are **non-permanent**, they will last from weeks to years according to conditions in the area (wind, rain, vegetation re-growth)

Burned Area

Algorithms for BA mapping

- **Visual interpretation** and application of **empirical spectral thresholds** to individual satellite bands (esp. pre- and post-fire)
- **Spectral band ratios**, esp. those based on NIR (~0.8 µm) and SWIR (~1.6-2.2 µm) reflectance (best differenciation)
- Automated methods

Burned Area

Algorithms for BA mapping

- Automated methods
  - definition of the **magnitude of spectral change** is critical
  - multi-temporal data and a **change detection scheme** to take advantage of the "temporal persistency" of fire effects
  - challenge is to **map only the fire-affected area** and not other changes: flooding, snow melt, rapid vegetation senescence, cloud shadows and ploughing of agricultural fields
  - **several methods used** at different scales applied to either multi-temporal or single images: supervised classifications (maximum likelihood, decision trees, random forest, SVM and neural networks), segmentation/OBIA, linear transformations (tasselled cap and PCA), spectral unmixing techniques, and logistic regression models

Burned Area

Algorithms for BA mapping in operative products

First BA products:

- Search for a **drop in SWIR & increase in TIR** plus multi-temporal criteria to reject false positives (NOAA-AVHRR, ATSR, MCD45)

Most recent BA products:

- **Hybrid algorithms** that use the AF to define the magnitude of spectral change associated with fire, so AF are used as seeds and BA are then mapped by contextual algorithms such as growing regions (MCD64, Fire_CCI)

Burned Area

Operative products

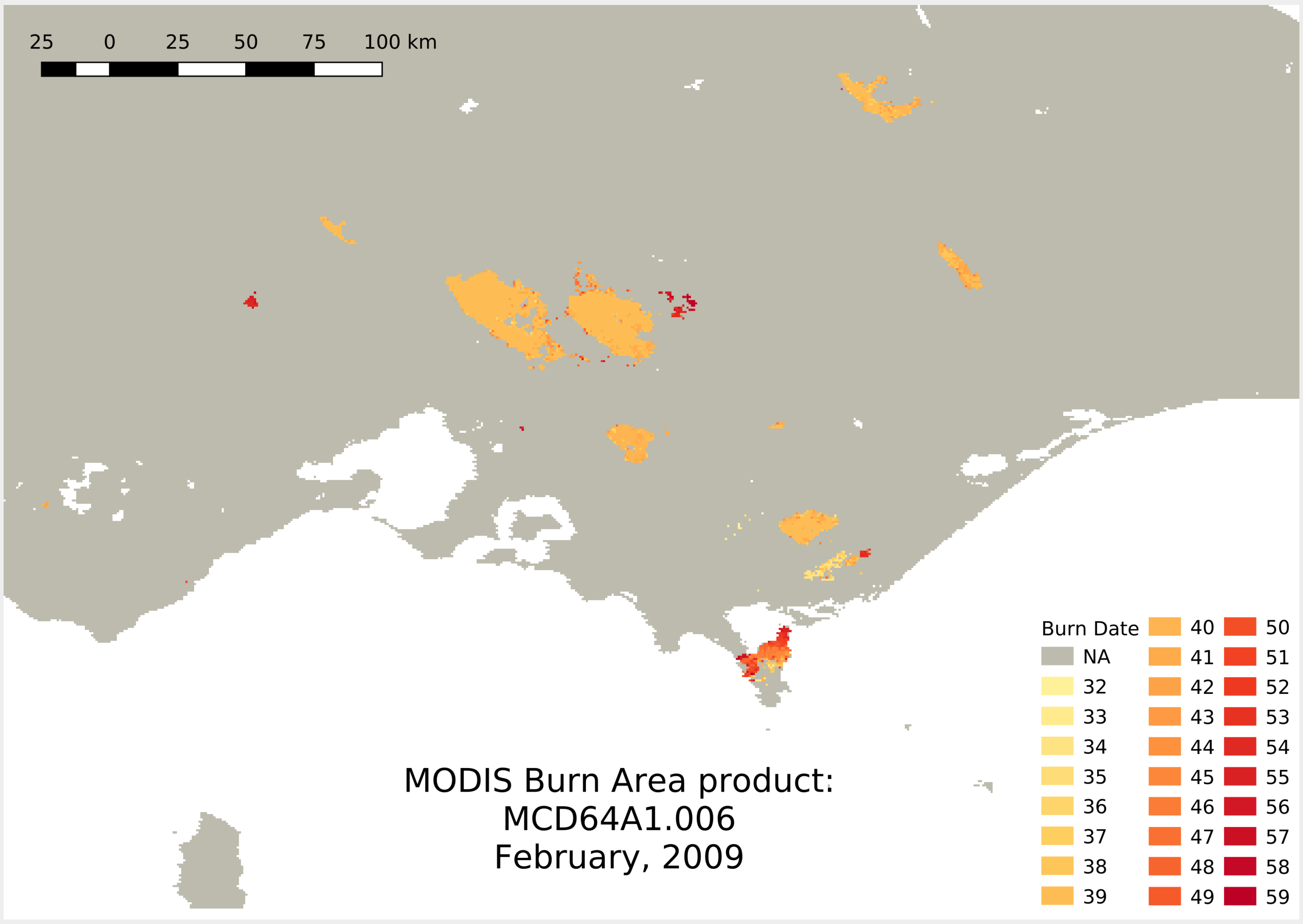
	Sensor	Time series	Spatial res	Type of algorithm/detection	Reference
MCD 45	MODIS Aqua Terra	2001–present	500 m	Bi-directional reflectance model-based change detection approach	Roy et al. (2005)
MCD 64	MODIS Aqua Terra	2001–present	500 m	HS and multi temporal spectral indices changes	Giglio et al. (2009)
GBA 2000	SPOT VGT	11/1999–12/2000	1 km	Multi temporal changes in daily reflectances or spectral indices (IFI and UTL algorithms)	Ershov and Novik (2001) Silva et al. (2003) Grégoire, Tansey, and Silva (2003)
GBS	NOAA AVHRR	1982–1999	8 km	Multi temporal change detection	Carmona-Moreno et al. (2005)
GLOB SCAR	ERS2 ATSR2	2000	1 km	K1: contextual algorithm based on geometrical characteristics of burned pixels in the near-infrared (NIR, 0.87 µm)/thermal infrared (TIR, 11 µm). E1: series of fixed thresholds applied to the data from four spectral channels.	Piccolini and Arino (2000) Eva and Lambin (1998)
GLOB CARBON	ERS2 ATSR2 SPOT VGT ENVISAT AATSR	1998–2007	1 km	Based on two GBA2000 algorithms: IFI and UTL and two GLOBSCAR algorithms: K1 and E1.	
L3JRC	SPOT VGT	2000–2007	1 km	Temporal index, based on GBA2000 experience.	Tansey et al. (2008)
GEO LAND2	SPOT VGT	1999–present	1 km	Temporal index and thresholds	(http://www.geoland2.eu/ last accessed November 26, 2014)

Source: Alonso-Canas & Chuvieco (2015)

Links to BA products' websites: GLOBSCAR, GLOBCARBON, GBA2000, L3JRC, MCD45A1, MCD64A1, ESA Fire_CCI, GFED, GBS.

Burned Area

Operative products



Burned Area

Application of BA products

- Fire hazard assessment for ecosystem management (daily products, finer spatial resolution for better delineation of fire contours and long time series for better understanding of fire regime)
- Early warning fire alert systems and survey (better timing and low omission errors)
- Atmospheric chemistry
- Biogeochemical models
- Dynamic global vegetation models

Burned Area

Accuracy of BA products

- Limitations to detect small fires (thresholds observed range between 100 and 120 ha)
- Limitations to detect low intensity fires (common in savannas, agricultural fields and shrublands)
- Accuracies can fall to 40% in some biomes or when using coarser resolution sensors
- Issues of temporal reporting

Fire regime

Fire regime is described by:

- Frequency
- Seasonality
- Spread pattern
- Intensity
- Fuel consumption
- Severity

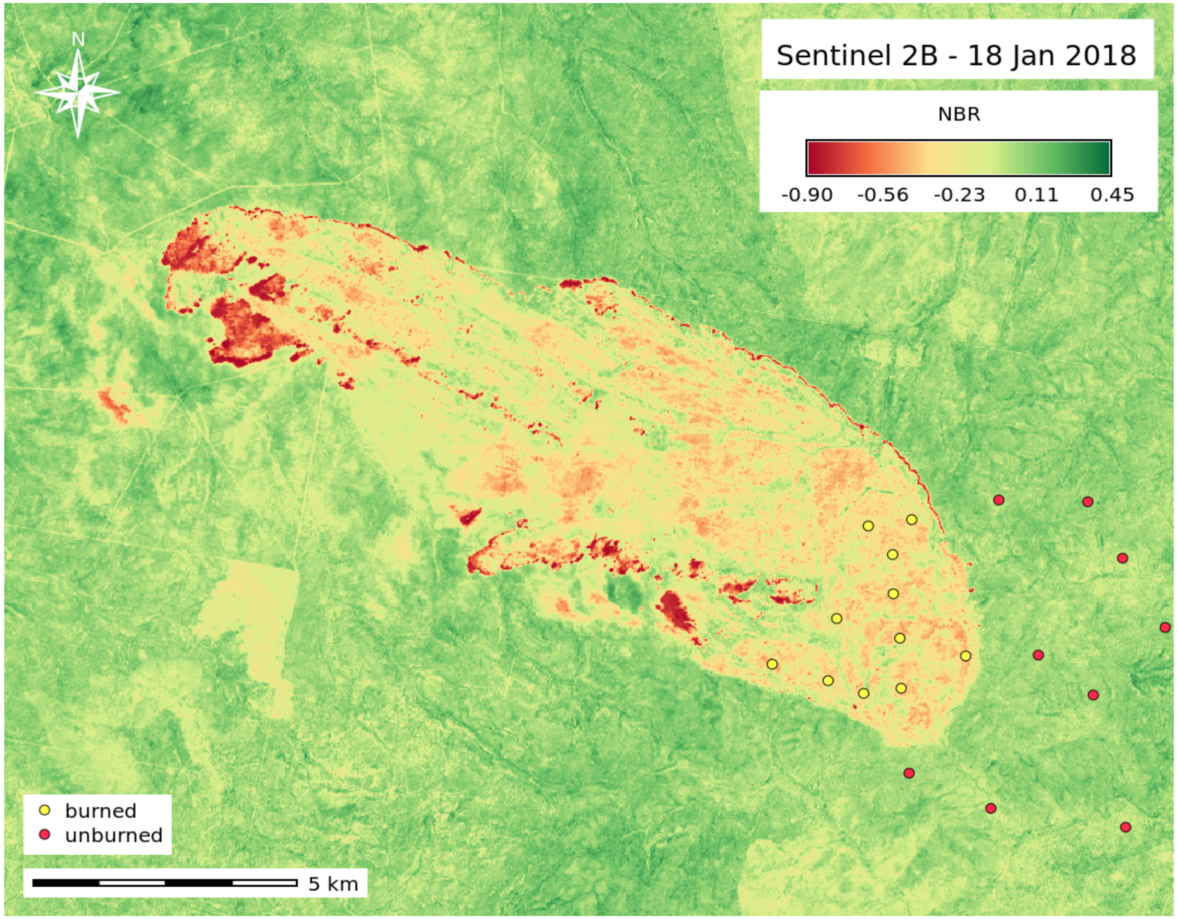
Spectral Indices

Based on the differences in the spectral signature of burned and unburned vegetation

- **Burned Area Index**: BAI = 1 / (NIR - 0.06)^2 + (RED - 0.1)^2
- **Global Environmental Monitoring Index**: GEMI = η (1 – 0.25 η) – (RED – 0.125) / (1 – RED)
- **Burned Area Index Modified**: BAIM = 1 / ((NIR - 0.05)^2 + (SWIR - 0.2)^2)
- **Normalized Burned Ratio**: NBR = (NIR – SWIR) / (NIR + SWIR)
- **Mid-Infrared Burned Index**: MIRBI = 10 * SWIRL - 9.8 * SWIRS + 2

NDVI, **EVI** and **LST** are also used, as well as combinations such as LST/EVI or d(LST/EVI)

References:
η = (2 * (NIR^2 - RED^2) + 1.5 NIR + 0.5 RED) / (NIR + RED + 0.5)
RED: Red reflectance
NIR: Near Read Infrared reflectance
SWIR: might be SWIRS or SWIRL
SWIRS: Short Wave Infrared Short reflectance (~ 1.6 μm)
SWIRL: Short Wave Infrared Long reflectance (~ 2.2 μm)



Sentinel 2B - 18 Jan 2018
NBR
-0.90
-0.56
-0.23
0.11
0.45
N
burned
unburned
5 km

Indices for Landsat TM/ETM+ & Landsat 8

Selected indices and calculation algorithm, using Landsat 8 OLI/TIRS bands or Landsat 7 ETM + bands.

Spectral index		Landsat 8 OLI/TIRS formula	Landsat 7 ETM + formula	Reference
Reflective	NBR	$(\rho_5 - \rho_7) / (\rho_5 + \rho_7)$	$(\rho_4 - \rho_7) / (\rho_4 + \rho_7)$	López-García and Caselles (1991)
	dNBR	$1000\ (NBR_{pre} - NBR_{post}) - offset$[a]	$1000\ (NBR_{pre} - NBR_{post}) - offset$[a]	Key (2006)
	RdNBR	$dNBR / (\lvert NBR_{pre} \rvert^{0.5})$	$dNBR / (\lvert NBR_{pre} \rvert^{0.5})$	Miller and Thode (2007)
	RBR	$dNBR / (NBR_{pre} + 1.001)$	$dNBR / (NBR_{pre} + 1.001)$	Parks et al. (2014)
	NDVI	$(\rho_5 - \rho_4) / (\rho_5 + \rho_4)$	$(\rho_4 - \rho_3) / (\rho_4 + \rho_3)$	Rouse et al. (1973)
	dNDVI	$NDVI_{pre} - NDVI_{post}$	$NDVI_{pre} - NDVI_{post}$	Zhu et al. (2006)
	EVI	$2.5\ [(\rho_5 - \rho_4) / (\rho_5 + 6\rho_4 - 7.5\rho_2 + 1)]$	$2.5\ [(\rho_4 - \rho_3) / (\rho_4 + 6\rho_3 - 7.5\rho_1 + 1)]$	Gao et al. (2000)
	dEVI	$EVI_{pre} - EVI_{post}$	$EVI_{pre} - EVI_{post}$	Zhu et al. (2006)
	dNBR-EVI	$(dNBR\text{-}EVI * 1000) - offset$[a]	$(dNBR\text{-}EVI * 1000) - offset$[a]	Proposed by the authors
Thermal	LST	LST in Kelvin from $B_{10}(T_s)$	LST in Kelvin from $B_{6L}(T_s)$	Yu et al. (2014)
	dLST	$LST_{post} - LST_{pre}$	$LST_{post} - LST_{pre}$	Zheng et al. (2016)
Mixed	LST/EVI	$(LST - 273.15)/EVI$	$(LST - 273.15)/EVI$	Zheng et al. (2016)
	d(LST/EVI)	$(LST/EVI)_{post} - (LST/EVI)_{pre}$	$(LST/EVI)_{post} - (LST/EVI)_{pre}$	Zheng et al. (2016)

[a] Offset is the average index value from pixels in homogeneous and unchanged areas.

Source: Fernandez-Garcia et al. (2018)

Spectral Indices for Sentinel 2

Acronym	Spectral Index	Equation
Reference spectral indices		
NDVI	Normalized Difference Vegetation Index	$\frac{(B8-B4)}{(B8+B4)}$
NBR	Normalized Burn Ratio	$\frac{(B8-B12)}{(B8+B12)}$
GNDVI	Green Normalized Difference Vegetation Index	$\frac{(B8-B3)}{(B8+B3)}$
SR	Simple Ratio	$\frac{B8}{B4}$
DVI	Difference Vegetation Index	$(B8-B4)$
Red-edge spectral indices		
NDVIre1	Normalized Difference Vegetation Index red-edge 1	$\frac{(B8-B5)}{(B8+B5)}$
NDVIre1n	Normalized Difference Vegetation Index red-edge 1 narrow	$\frac{(B8a-B5)}{(B8a+B5)}$
NDVIre2	Normalized Difference Vegetation Index red-edge 2	$\frac{(B8-B6)}{(B8+B6)}$
NDVIre2n	Normalized Difference Vegetation Index red-edge 2 narrow	$\frac{(B8a-B6)}{(B8a+B6)}$
NDVIre3	Normalized Difference Vegetation Index red-edge 3	$\frac{(B8-B7)}{(B8+B7)}$
NDVIre3n	Normalized Difference Vegetation Index red-edge 3 narrow	$\frac{(B8a-B7)}{(B8a+B7)}$
PSRI	Plant Senescence Reflectance Index	$\frac{(B4-B3)}{B6}$
CIre	Chlorophyll Index red-edge	$\frac{B7}{B5}-1$
NDre1	Normalized Difference red-edge 1	$\frac{(B6-B5)}{(B6+B5)}$
NDre1m	Normalized Difference red-edge 1 modified	$\frac{(B6-B5)}{(B6+B5-2B1)}$
NDre2	Normalized Difference red-edge 2	$\frac{(B7-B5)}{(B7+B5)}$
NDre2m	Normalized Difference red-edge 2 modified	$\frac{(B7-B5)}{(B7+B5-2B1)}$
SRre1	Simple Ratio red-edge 1	$\frac{(B6-B1)}{(B5-B1)}$
SRre2	Simple Ratio red-edge 2	$\frac{(B7-B1)}{(B5-B1)}$
MSRre	Modified Simple Ratio red-edge	$\frac{(B8/B5)-1}{\sqrt{(B8/B5)+1}}$
MSRren	Modified Simple Ratio red-edge narrow	$\frac{(B8a/B5)-1}{\sqrt{(B8a/B5)+1}}$

Acronym	Band	Central wavelength (nm)
Original spectral bands		
B2	Blue	490
B3	Green	560
B4	Red	665
B5	Red-edge 1	705
B6	Red-edge 2	740
B7	Red-edge 3	783
B8	NIR	842
B8a	NIR narrow	865
B11	SWIR1	1610
B12	SWIR2	2190

Indices based on **red-edge bands** from S2 resulted better qualified for BA mapping and burn severity discrimination

Source: Fernandez-Manso et al. (2016)

Burn Severity

Burn severity is of great value in defining **emergency areas**, especially in those ecosystems dominated by obligate seeders or with high vulnerability to soil erosion. It is also important in the context of **post-fire remediation**: subsidies, help, tax exemptions.

Severity is estimated with bi-temporal spectral indices considering **pre- and post-fire** scenes, for example:

- **dNBR** = NBRpre-fire - NBRpost-fire * 1000
- **RdNBR** = deltaNBR / sqrt(abs(NBRpre-fire))
- **RNBR** = deltaNBR / NBRpre-fire + 1.001
- **d(LST/EVI)** = LSTpost-fire / EVIpost-fire - LSTpre-fire / EVIpre-fire
- **dNBR-EVI** = (dNBR - EVI * 1000) - offset

Online AF and BA monitoring and risk forecast systems

- GWIS
- GFED
- FIRMS
- GFW
- Sentinel Hotspots (AU)
- MTBS (CONUS)
- Firenorth (North AU)
- FFDI (Argentina)
- CWFIS (Canada)

Latest developments in BA mapping

New algorithms are being developed and tested in order to produce global BA products at regional/landscape scale:

- Landsat TM/ETM+ and Landsat 8 OLI
  - **Web Enabled Landsat Data (WELD)** for CONUS on a weekly and annual basis & **Analysis ready data (ARD)** for CONUS, Alaska & Hawai
  - **Landsat Burned Area Esential Climate Variable (BAECV)** for CONUS. Period 1984-2017. (Gradient boosted regression models)
- Merged Landsat + Sentinel 2
- Sentinel (1 and 2)

Thanks much for your attention!