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BAMT

Burned Area Mapping Tools in Google Earth Engine

Version 1.6 – User Guide

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Index

1 Introduction

Reference data are essential when developing an algorithm, as the derived product will have to be compared and assessed with some "perfect" reference. The best perimeters would be those measured on the ground, which is very costly and requires too much time, so the other option is generating these data by the user.

Aitor Bastarrika developed a software to detect burned areas (BA): Burned Area Mapping Software or BAMS (Bastarrika et al., 2014), formerly downloadable at https://bastarrika.wordpress.com/. It was a semi-automatic BA mapper based on ArcGIS, applying a two-phase algorithm on Landsat images. It required the user to download and save all the necessary Landsat images, which could sometimes be annoying.

In order to avoid these inconveniences, Google developed a cloud-computing platform to process satellite data: Google Earth Engine (https://earthengine.google.com/). This includes access to a large database of satellite datasets, no need to store big amounts of data and a powerful ability of data processing. Taking advantage of all of this and following the idea of BAMS, several tools have been developed in Google Earth Engine (GEE). No input data need to be downloaded, the whole processing is carried out in the cloud, and only the final results are exported and optionally downloaded; the only requirement is a good internet connexion.

The original BAMS software generated reference data in a Landsat scene between two consecutive dates; here, we have expanded it to cover the entire process of BA mapping, while including also Sentinel-2 images to improve both the temporal and spatial resolutions. They are called **Burned Area Mapping Tools** or ***BAMT***, and can be used by anyone with a Google account and signed up in the Google Earth Engine platform. The four main **BAMT** tools are:

1) **BA Cartography** tool: for creating BA products over large areas and a long temporal span, between two periods used as the pre- and post-fire spectral signals.
2) **VA** tool: validation area searcher for assessing the BA product by the previous tool, based on a previous study's methodology (Padilla et al., 2014). This tool samples the best validation areas based on the total burned surface, the biome and data availability in each area.
3) **VA Dates** tool: after identifying the validation areas with the previous tool, this one just signals which dates should be used in each validation area for creating reference perimeters.
4) **RP** tool: for generating high-quality reference perimeters between two consecutive images, selected from the previous tool's results.

But there is also an extra tool, not related to BA mapping:

5) **Image Viewer**: a tool that displays Landsat and Sentinel-2 images from any period and place in the world.

All results are exported to the Google Drive account of the user, where a folder called *BAMT_GEE* is created. Every file carries an identifier specified in each tool by the user, in order to distinguish files from different projects.

1.1 Datasets

Several datasets are used by these tools, all of them belonging to one of two large Earth observation satellite missions or programmes: Landsat and Sentinel.

The **Landsat** program is a NASA/USGS program for satellite imagery acquisition and Earth observation (https://www.usgs.gov/land-resources/nli/landsat, last accessed in April 2020). From its seven historical and current satellites, the last four are used in these tools:

- **Landsat-4**, with the Thematic Mapper or **TM** sensor
- **Landsat-5**, whith the Thematic Mapper or **TM** sensor
- **Landsat-7**, whith the Enhanced Thematic Mapper Plus or **ETM+** sensor
- **Landsat-8**, whith the Operational Land Imager or **OLI** sensor

These four satellites currently cover a temporal span of 38 years, from July 1982 to the present, with each satellite acquiring images over the Earth at 30 m of spatial resolution every 16 days; the temporal resolution improves if different satellites are combined. Whenever one of these datasets is chosen, the Landsat Surface Reflectance (LSR) product will be used (https://www.usgs.gov/land-resources/nli/landsat/landsat-surface-reflectance, last accessed in April 2020), which consists in geometrically corrected images with Bottom-of-Atmosphere reflectances (BOA) for every band.

The **Sentinel-2** mission (S2) is part of the Copernicus Programme and developed by ESA (European Space Agency) for Earth Observation, (http://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-2, last accessed in April 2020), consisting of twin satellites Sentinel-2A and Sentinel-2B. The same sensor, the Multi-Spectral Instrument or **MSI**, is carried by both satellites. The first satellite (Sentinel-2A) was launched in June 2015, so the mission currently covers a temporal span of 5 years, acquiring images first every 10 days and then every 5 days from March 2017 on (when the satellite Sentinel-2B was launched). The spatial resolution varies among 10, 20 and 60 depending on the spectral band; any S2 product by these tools is generated at 20 m.

Whenever the Sentinel-2 dataset is selected in the BAMT tools, the Level-1C or L1C product is used (https://sentinel.esa.int/web/sentinel/user-guides/sentinel-2-msi/product-types/level-1c, last accessed in April 2020), which contains orthorectified images with Top-of-Atmosphere (TOA) reflectances. The Level-2A or L2A product (https://sentinel.esa.int/web/sentinel/user-guides/sentinel-2-msi/product-types/level-2a, last accessed in April 2020) contains Bottom-of-Atmosphere reflectances and an accurate classification of the image called Scene Classification (SCL), but it is not fully available yet in the Earth Engine Data Catalog. Besides, it was observed that some L2A images have some artificial effects in mountainous areas, resulting from a topographic overcorrection of mountain shadows (Figure 1), so the L1C product is preferred here.

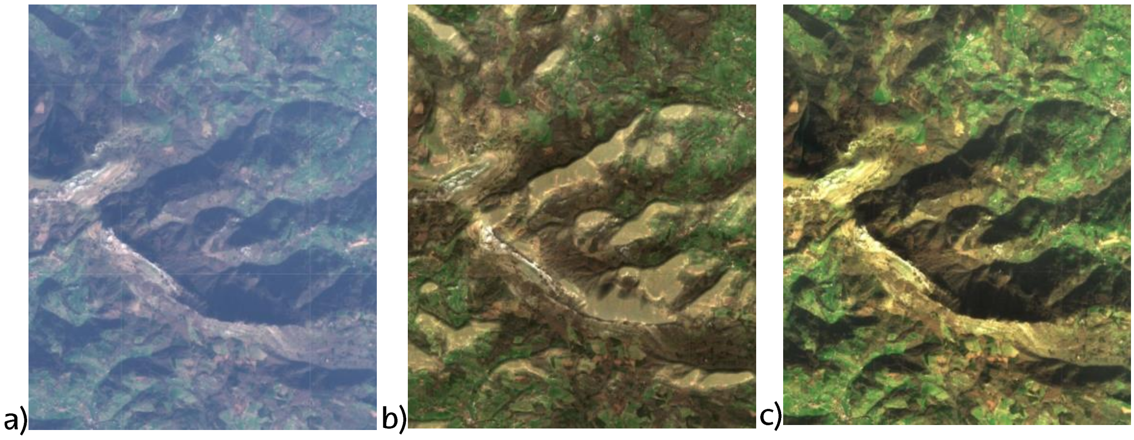


Figure 1. Sample area in a mountainous region from 3rd February 2020, tile 30TWN, where the artificial effect can be seen in mountain shadows. a) L1C product with TOA reflectances, b) L2A product with BOA reflectances as available in GEE, and c) the same L2A product generated independently with no topographic correction.

Six spectral bands are used in all BAMT tools for both Landsat and Sentinel-2 datasets: the visible colours (blue, green and red), the near infrared (NIR) and two short wavelength infrareds (Short and Long SWIR). The near infrared B8A band, originally at 20 m, is used in most cases for S2 images; however, the B8 band at 10 m is selected as near infrared when the RP are created at that same resolution. Table 1 shows the corresponding bands in each satellite and sensor.

Table 1. Bands selected for BAMT tools, depending on the satellite and sensor.

Satellite	Landsat-4 and 5	Landsat-7	Landsat-8	Sentinel-2A and 2B	
Sensor	TM	ETM+	OLI	MSI	
Product	LSR			L1C	L2A
Blue	B1	B1	B2	B2	
Green	B2	B2	B3	B3	
Red	B3	B3	B4	B4	
NIR	B4	B4	B5	B8A (20 m) B8 (10 m)	
Short SWIR	B5	B5	B6	B11	
Long SWIR	B7	B7	B7	B12	
Quality band	pixel_qa			QA60	SCL

When clouds and cloud shadows need to be masked in any tool, quality bands are selected. For Landsat datasets the band *pixel_qa* is used, whose 3rd and 5th bits indicate the presence of cloud shadows and clouds, respectively. Sentinel-2 images have a similar quality band called *QA60*, with the same information in bits 10 and 11 (Table 1).

However, the Scene Classification (SCL) is preferable for S2 images when the L2A is available, since the SCL has more categories and is spatially more accurate than the QA60 band. This is not feasible for the *BA Cartography* tool, where there may be thousands of images and coupling SCL bands from L2A products to the corresponding L1C images will exceed GEE's memory limit. But the SCL is used instead of the QA60 bands in the *RP* tool whenever the L2A product is available, where only two images are used by the entire tool.

2 BA Cartography tool

https://code.earthengine.google.com/1ed80f3e5190630b1395fa509b95b9ee

This main tool generates a burned area product over a large region and during a long temporal period, via a supervised classification. A polygon must be defined for the extent of the region, while the temporal period will be delimited by two dates.

The process consists on training a Random Forest classifier, using various spectral bands and indices from the post-fire image and from a multitemporal difference image. This classifier returns an image with a probability value from 0 % (unburned) to 100 % (burned) for every pixel. A two phase algorithm is applied upon this image, first identifying burned seeds (pixels with a very strong burned signal) and then extending the burned areas around these seeds. The burned areas can be exported in the ESRI Shapefile format, with an attribute indicating the date of detection of the burned area.

2.1 Initial parameters

Before detecting burned areas, the user must define some initial parameters, which will fix the dates of the temporal periods, the geographic region and the dataset to be used. All these variables are defined at the beginning of the script, between lines 6 to 25.

The burned areas are detected comparing two temporal composites corresponding to the pre-fire and post-fire periods; the post-fire period begins exactly the day the pre-fire period ends. Thus, three different dates must be defined:

- ***date_1***: the beginning of the pre-fire period.
- ***date_2***: the end of the pre-fire period and the beginning of the post-fire period.
- ***date_3***: the end of the post-fire period.

All three dates must belong to the **String** data type and be written in this format:

YYYY-MM-DD

where YYYY stands for the year, MM for the month and DD for the day of the month, all of them differentiated with hyphens.

The dataset to be used for the product will be specified in the ***dataset*** variable. If '*Landsat*', all available images from sensors L4 TM, L5 TM, L7 ETM+ and L8 OLI will be used at 30 m; otherwise, with the '*Sentinel*' value, data from the S2 MSI sensor, L1C product, will be chosen, with a 20 m spatial resolution.

The geographical region is defined manually as a polygon. There is a *Geometry Input* layer called ***studyArea*** for this purpose (Figure 2); if you are not familiar with the *Geometry tools*, please visit the page https://developers.google.com/earth-engine/playground#geometry-tools (last accessed in April 2020). Any pre-existing polygon should be removed from this layer before defining a new region.

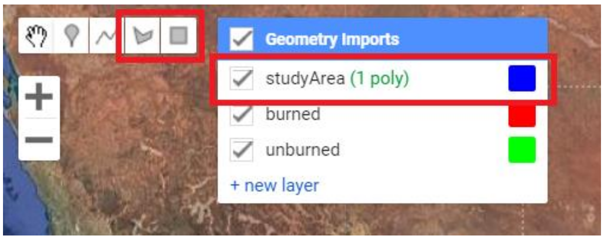


Figure 2. The *region_manual* layer to be used when the region must be defined manually as a polygon.

Finally, the user can write an ID in the ***identifier*** variable to differentiate this BA product from others, since this ID will appear in the names of the exported files. The last three variables, ***UMLError_tiles_1d***, ***UMLError_tiles_05d*** and ***UMLError_tiles_025d*** should be ignored and left as empty lists for now.

2.2 First layers

Once all the previous variables are defined, the user can press the button ***Run*** to execute the script.

The pre-fire and post-fire temporal composites are generated at this moment. For each period's composite, all available images from the region between the corresponding dates are selected, and clouds and cloud shadows are masked based on the quality band (*pixel_qa* in Landsat images, *QA60* for Sentinel-2 data). After computing the Normalized Burn Ratio or NBR spectral index, the composite is created by maximizing this index in every pixel. For the post-fire period another image is created, with the date from which each pixel was extracted. This image represents for every pixel the date when the highest NBR value was registered, and it will later be used as the date of detection of burned areas.

Six spectral bands are selected in both composites (Table 1): the three visible bands (blue, green and red), the near infrared (NIR), and both short wavelength infrareds (short and long SWIRs). Aside from those 6 bands, 3 spectral indices based on normalized differences are computed as well for both composites:

- Normalized Difference Vegetation Index (NDVI) (Rouse et al., 1974)

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

- Normalized Burn Ratio (NBR) (Key and Benson, 1999)

$$NBR = \frac{LongSWIR - NIR}{LongSWIR + NIR}$$

- Normalized Burn Ratio 2 (NBR2) (García and Caselles, 1991)

$$NBR2 = \frac{LongSWIR - ShortSWIR}{LongSWIR + ShortSWIR}$$

At the same time, when the script is executed and the composites created, several layers are shown in the *Layer manager* and in the map:

- ***Exportable tiles***: the grid used later to export results, explained in section 2.4.
- ***Pre-fire***: a colour composition of the pre-fire composite, with the Long SWIR, NIR and Red bands corresponding to the RGB colours.
- ***Post-fire***: a colour composition of the post-fire composite, with the Long SWIR, NIR and Red bands corresponding to the RGB colours.
- ***Difference***: a simple difference between both colour compositions, $image_{post\text{-}fire} - image_{pre\text{-}fire}$.
- ***MCD64A1*** and ***FireCCI51***: areas burned during the post-fire period according to the MCD64A1 c6 (Giglio et al., 2018, 2009) and FireCCI51 (Lizundia-Loiola et al., 2020) products, at 500 and 250 m respectively. As these products are only available from November 2000 and January 2001 on, the layers are not shown in the map for earlier dates.

A new button is printed in the *Console*:

- ***Zoom to region***: a general zoom to the region.

2.3 BA detection

Once some burned and unburned training polygons are defined using the available ***burned*** and ***unburned*** layers as *Geometry Imports* (Figure 3), burned areas can be detected for the first time. It is recommended to define polygons instead of rectangles, adjusting their shapes to burned areas; at the same time, defining large polygons can later slow down the process. At least one training polygon is required for each class; otherwise a new polygon will be asked to be defined.

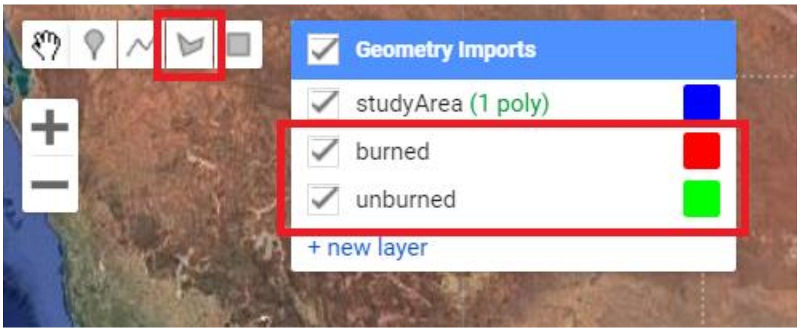


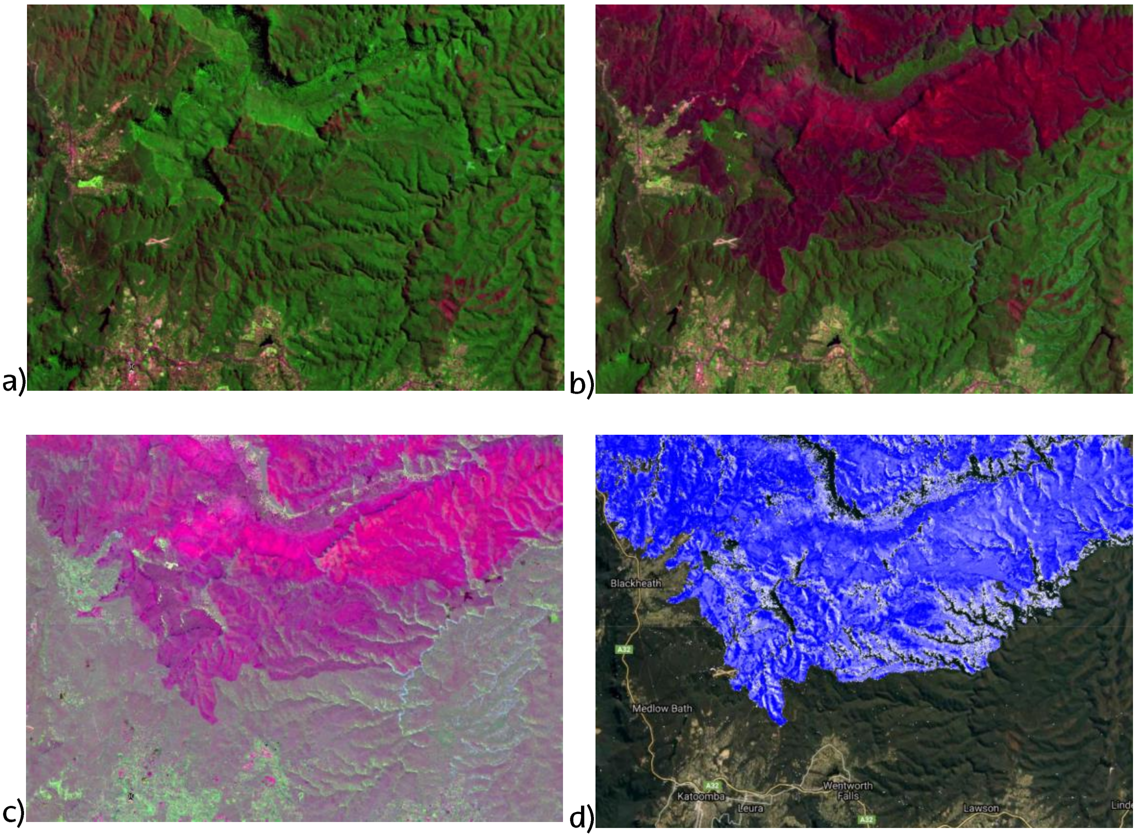
Figure 3. The layers to be used to define training polygons.

After pressing the ***Run*** button, burned areas are detected based on the training polygons. These areas are classified by a Random Forest classifier with 100 decision trees and nodes with a minimum of 10 leaves; the classifier is trained by all pixels contained in the training polygons. A total of 18 variables are introduced, the original 6 bands (blue, green, red, NIR and both SWIRs) and 3 spectral indices (NDVI, NBR and NBR2), each one of them twice: the post-fire value, and the difference between the pre- and post-fire values.

The result returned by the classifier is a probability image with values from 0 % (unburned) to 100 % (burned). Burned seeds are extracted from this image, representing pixels with the strongest burned signal; the threshold used here is the average of the mean burned probabilities in every burned training polygon.

Two new layers are now added to the *Map* (Figure 4):

- ***BA***: the probability image. To make easier its visualisation, a threshold of 50 % is applied to this image before being displayed, so that unburned pixels are transparent and the image at the bottom can be seen. Burned pixels are displayed with a colour palette from white (probability values close to 50 %) to blue (100 % probability of burned).
- ***Seeds***: the seeds extracted from the previous probability image in a red colour.



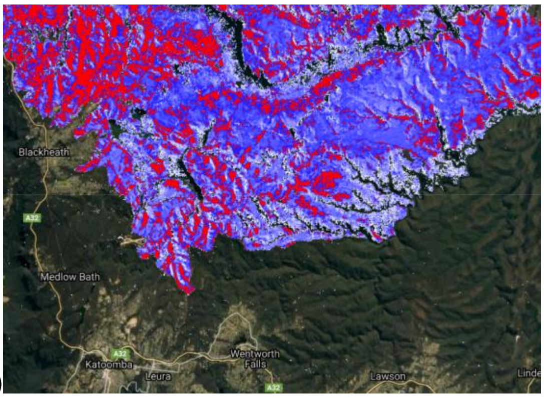
e)


Figure 4. Sample area west of Sidney, in Australia, with Landsat data. a) pre-fire composite of the September-October 2019 period, b) post-fire composite of the November-December 2019 period, c) difference image between both periods, d) probability of burn image with the Google Satellite image in the background, and e) the seeds in red shown on the previous image.

The user can now modify or define new training polygons until the desired results are obtained, pressing the ***Run*** button at each iteration to update the BA. Not all pixels with a probability higher than 50 % are exported in the end; burned areas are expanded from seeds outwards up to a 50 % threshold (section 2.4). Thus, the user should keep in mind that burned areas in layer ***BA*** will not be exported if they do not contain any seed.

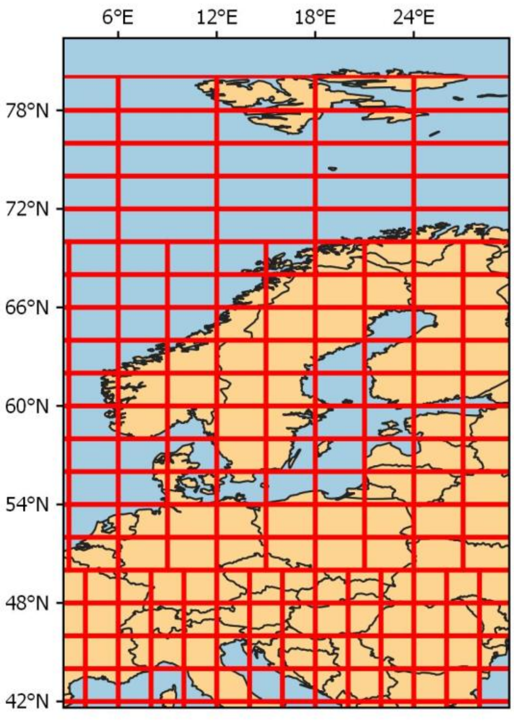
2.4 Exporting results

When the desired result is finally achieved, it can be exported to the user's Google Drive account by the two new buttons in the *Console*:

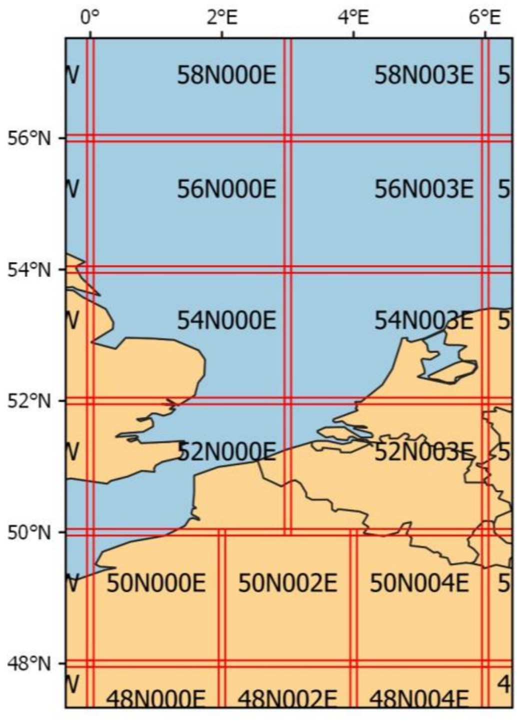
- ***Export BA***: the whole final BA product is exported in ESRI Shapefiles. The polygons have only one attribute, *BurnDate*, which is the day of detection of the burned area in the YYYYMMDD format, where YYYY stands for the year, MM for the month and DD for the day of the month. Areas not observed in either the pre-fire or the post-fire period (usually due to clouds and cloud shadows) are assigned a 0 value instead of a date; unburned pixels are not represented in these files.

- ***Export probability images***: the probability of burn image resulting from the Random Forest classifier is exported in GeoTIFF format, with values ranging from 0 to 100.

Due to GEE's memory limits, the whole product cannot be exported in a single file when BA are detected in a large study area. To solve this, the product (both the shapefile and the probability image) is exported in a regular grid between latitudes 60°S and 80°N (Figure 5a). All tiles from this grid are 2 degrees high, but their width depends on the latitude: 2 degrees between latitudes 50°S-50°N, 3 degrees between 50°-70° in both hemispheres, and 6 degrees between 70°-80°N. There is an overlapping area of 0.1 degrees between adjacent tiles. The ID of each tile contains the latitude and the longitude of the upper left corner (Figure 5b). This grid can be seen in the GEE map by activating the layer '***Exportable tiles***'.



a)



b)

Figure 5. a) the composition of the grid in a sample area in Central and North Europe where different widths of tiles can be seen depending on the latitude, and b) a zoom in Western Europe where the tile IDs can be seen.

Thus, these are the names of the exported files:

1) **BAMT_BA_*ID_SENSOR_DATE1-DATE2*_TILE-*TILEID*_SHP.shp**
2) **BAMT_BA_*ID_SENSOR_DATE1-DATE2*_TILE-*TILEID*_TIF.tif**

where:

- **ID**: the identifier defined by the user.
- **SENSOR**: *S2MSI* or *Lndst*, depending on the used dataset, corresponding to Sentinel-2 MSI and Landsat respectively.
- **DATE1**: the beginning of the post-fire period, in *YYYYMMDD* format.
- **DATE2**: the end of the post-fire period, in *YYYYMMDD* format.
- **TILEID**: the ID of the tile, indicating the latitude and longitude of the upper left corner.

After pressing the button ***Export BA*** or ***Export probability images***, the files to be exported will appear in the *Tasks* tab. The user must press the button ***Run*** next to these files or tasks one by one, and they will be exported to the user's Google Drive account, in a folder called *BAMT_GEE*.

As told before, there may be some slight differences between the burned areas displayed in the GEE API map and those exported in shapefiles to Google Drive. A two-phase algorithm is applied on the RF probability image before vectorizing it, with the aim to reduce noise. In the first phase burned seeds are extracted from the probability image, as already explained. In a second phase, the burned areas are expanded from these seeds outwards up to a 50 % threshold. These grown burned areas are then polygonized and exported.

The post-fire temporal composite was created by maximizing the NBR spectral index over the whole period, which means that every pixel may have its origin in a different date. As the final burned polygon should only have one day of burn, the modal date among all the pixels is assigned to the polygon, i.e. the most repeated date. This is the value represented by the *BurnDate* attribute. Polygons split between two adjacent tiles may display different dates of burn, even if they are clearly part of the same burned area, because they are composed by different pixels and the most repeated date may have changed.

Despite splitting the BA product in 2 degree tiles, the burned polygons in a single tile are sometimes too heavy to export, and the processing fails with the task turning red and showing a message of '*Error: User memory limit exceeded*' or '*Error: Computation timed out*' (Figure 6).

a)


b)

Figure 6. Errors shown every time '*user memory limit exceeded*' or '*computation timed out*'.

In those cases the 2 degree tile must be split in smaller subtiles; this is when the ***UMLError_tiles_1d*** variable must be used. The IDs of the tiles that could not be exported should be written in this list, as *String* variables, and after running the script these tiles will be split in 4 smaller tiles, 1 degree high and wide (Figure 7). The new subtiles will be named with an index from 1 to 4 hyphenated to the ID of the parent tile.

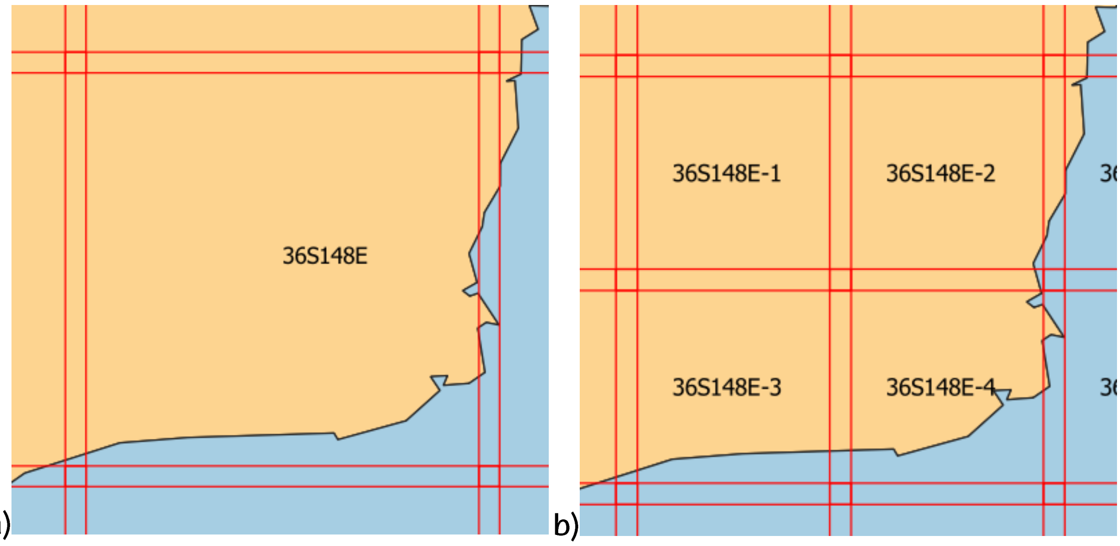


Figure 7. a) the original 2 degree tile with the upper left corner at latitude 36°S and longitude 148°E, in Southeast Australia, and b) the same tile split in four smaller subtiles.

If some of these 1 degree tiles cannot be exported yet, they can be split again in 0.5 degree tiles writing them in the ***UMLError_tiles_05d*** variable; or even farther by writing the undownloaded 0.5-degree tile in ***UMLError_tiles_025d*** and thus getting subtiles 0.25 degrees high and wide. The resulting grid can be seen at any moment in the map as the '***Exportable tiles***' layer (Figure 8).

a)
```
// Please list here the tiles that could not be downloaded because 'User memory limit
// exceeded':
var UMLError_tiles_1d = ['34S148E'];
// In case some 1 degree tiles cannot be downloaded yet, list them here:
var UMLError_tiles_05d = ['34S148E-3'];
// And if some 0.5 degree tiles cannot be downloaded yet, list them here:
var UMLError_tiles_025d = ['34S148E-3-3'];
```

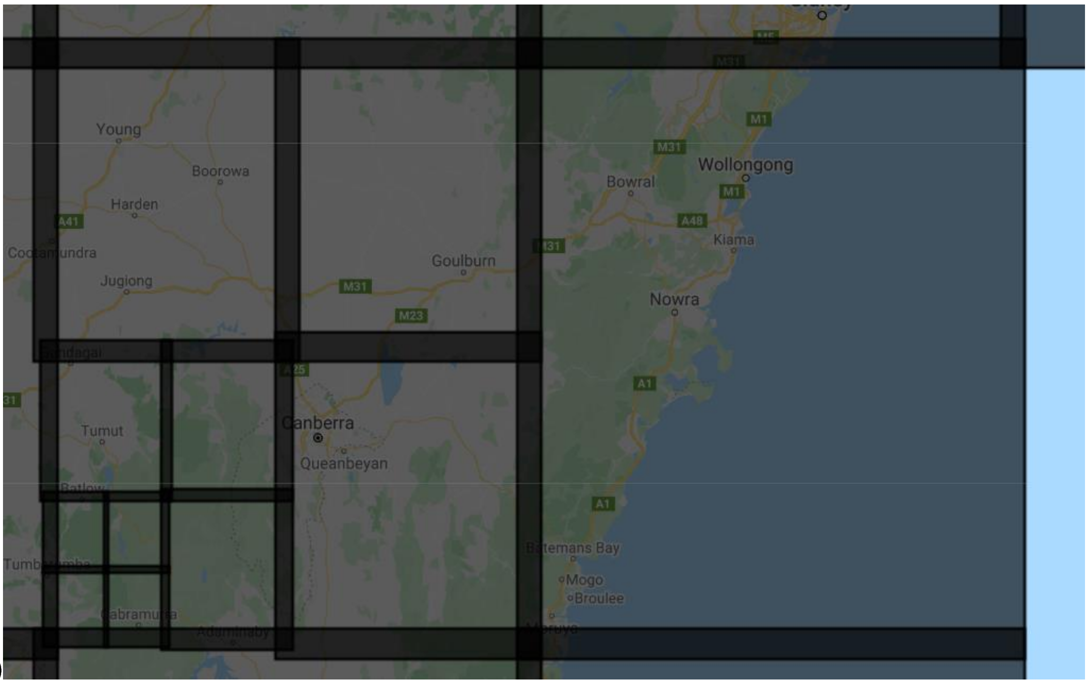
b)


Figure 8. a) Example of splitting a tile several times in the script, up to the point where subtiles 0.25 degrees high and wide are gotten; the original 2 degree tile's upper left corner is at 34°S 148°E around Canberra, Australia. b) Result of this splitting seen in the map; the tile to the East (ID 34S150E) remains unchanged.

Another common error is shown when every pixel in the entire tile is observed and unburned, so no polygon can be created and exported, which are either burned or unobserved areas. The task turns red with a message telling '*Error: Unable to write shapefile from empty collection*' (Figure 9). This shapefile is simply not exported to the user's Google Drive account.

Figure 9. Error shown when there is no polygon to be exported.

Finally, once the BA detected and all the necessary data exported, it is important not to forget to delete some polygons before beginning to detect BA elsewhere. The *studyArea* layer should not have more than a polygon at the same time, so the previous polygon should be removed before changing the region. As for burned and unburned training polygons, the tool filters these polygons spatially, so it is not necessary to delete them if the region is changed. They must be deleted, however, if the dates are changed but not the region, as pixels in training polygons will hardly correspond to the same burned/unburned class.

However, the training polygons can be saved in case the process must be repeated. It is as simple as saving a copy of the script with the *Save as...* button. While the user continues working in the original script, the region, the dates and the training polygons will be kept safe in the copy.

3 VA tool

https://code.earthengine.google.com/82e59f4d8dc7ea640c8db02e9ef60933

Every BA product should be assessed to evaluate its accuracy, for which reference data are needed in some validation areas (VA). This tool selects the best validation areas to assess the product, adapting a sampling methodology by several stratification criteria (Boschetti et al., 2016; Padilla et al., 2017) in Google Earth Engine. Later, the *RP* tool will be used to create reference data in these validation areas, derived either from Landsat or Sentinel-2 data.

3.1 Sampling units

The original methodology (Boschetti et al., 2016; Padilla et al., 2017, 2014) used Thiessen scene areas (TSA) (Cohen et al., 2010; Kennedy et al., 2010) based on Landsat scenes as sampling units. These cannot be used however with Sentinel-2 images, as many Landsat TSAs may be divided among several Sentinel-2 tiles or located on the edge of a S2 orbit swath, so S2 tiles are used instead when the user selects S2 data for creating reference perimeters.

Besides, both the TSAs and the S2 tiles are too large to process when creating reference data (around 170x150 and 110x110 km^2, respectively), so generating reference perimeters in a smaller central area of the TSA/tile is more suitable, as it will be easier to process for GEE. Thus, squares of 100x100, 50x50, 30x30, 20x20 and 10x10 km^2 have been created in the centre of every TSA and S2 tile to be used as sampling units (Figure 10); this way the user will choose the size of the validation areas. Note that the largest units, of 100x100 km^2, are nearly the same size as the original S2 tiles (110x110 km^2).

To avoid S2 sampling units divided between two orbits, units were removed when no orbit swath covered at least 95 % of the square's surface. Units far from the Equator may be covered by two or more orbits, increasing the temporal resolution.

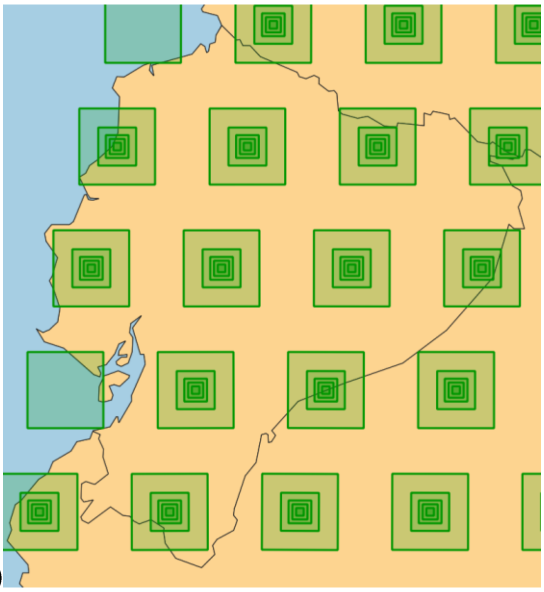
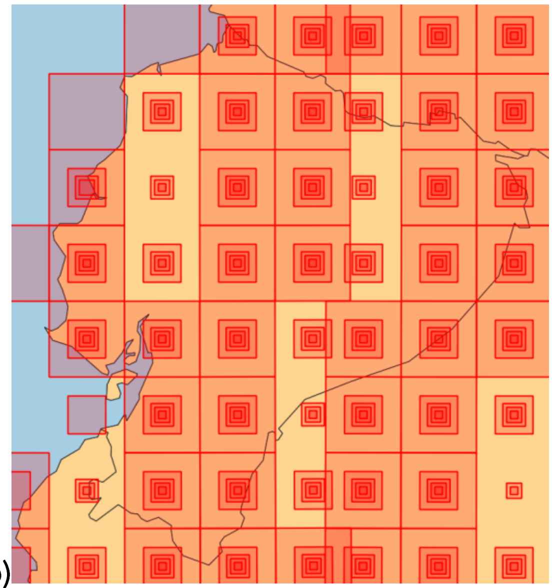
a)  b) 

Figure 10. Sampling units for a) Landsat and b) Sentinel-2 datasets over Ecuador. Gaps between S2 sampling units are caused by orbit swath edges.

3.2 Description of the tool

As the validation areas are needed to assess the BA product, the same temporal and spatial extensions as in the *BA* Cartography tool should be used here. The ***date_pre*** and ***date_post*** variables should be coincide with ***date_2*** and ***date_3*** of the previous tool, respectively, all of them in the '*YYYY-MM-DD*' format. In the same way, the poygon delimiting the BA product in the layer ***studyArea*** should be the same. Any pre-existing polygon should be removed from this layer before defining a new region.

The ***dataset*** variable will specify which sensor's data are to be used in the sampling of validation areas (and later when creating reference perimeters):

Landsat-4 TM, Landsat-5 TM, Landsat-7 ETM+, Landsat-8 OLI, all the previous four sensors (Landsat-4 to 8), or Sentinel-2 MSI. The user can write an ID in the ***identifier*** variable to differentiate this BA product from others, just as in the previous tool. The number of VA to sample is set by ***numberVA***, and the size (width and height) in km of each sampling unit and validation area by ***dimension***.

The original sampling methodology applies two stratification criteria:

1) The predominant Olson biome (Olson et al., 2001). The original 14 biomes are classified in seven categories to simplify the process.
2) The burned surface in each sampling unit. In this case either the MCD64A1 c6 (Giglio et al., 2018, 2009) or the FireCCI51 (Lizundia-Loiola et al., 2020) product is used as a reference, which is specified by the user with the ***globalBA*** parameter.

However, a third stratification criterion is added in this tool, which includes data availability and cloudiness. This temporal criterion is optional, applied only when the variable ***temporalCriterion*** is **true**; if **false**, only the first two criteria are used. Including this temporal criterion may slow down the sampling process or exceed the memory limit with large study areas or long temporal periods, but it should be included as far as possible.

With this criterion, the user can require sampling units to contain a temporal period of a minimum length of ***samUnitLength*** days, during which there is an available image every ***freq*** days, each one of them with a cloud coverage lower than the given ***cloudThr*** threshold. This way a continuous and frequent observation of the ground is assured.

Unfortunately, computing the cloud coverage in every sampling unit and every single image in the temporal period requires too much processment for the GEE, so this information is taken from the image's metadata, which refers to the whole image. This means that the value used here is not exactly that of the sampling unit's area; but it is a good approximation.

Once all these parameters have been set properly, the script can be ***Run***, and three buttons are printed in the *Console*:

1) ***Zoom to region***: a general zoom to the region.
2) ***Show results***: processes the sampling methodology and shows the results.
3) ***Export results***: processes the sampling methodology and exports the results.

Upon pressing the button ***Show results***, the sampling methodology is carried out. If the temporal criterion is applied, sampling units fulfilling the three conditions (period's minimum length, minimum frequency and cloudiness threshold) will be filtered, removing those that do not; the remaining units are assigned the temporal period where the conditions were achieved. There may happen to be two or more sampling units in a single Landsat scene or S2 tile, each with its own period, if the BA product's period is long enough. If ***temporalCriterion*** is **false**, all the sampling units are kept, and the BA product's period is assigned to them (from ***date_pre*** to ***date_post***).

The other two stratification criteria are applied on the sampling units resulting from the temporal criterion. Each unit is assigned 1) the Olson biome that covers most of its area, and 2) the total burned surface according to the MCD64A1 or FireCCI51 product in the sampling unit's area during its period. Sampling units are divided between low and high BA substrata in each biome, and validation areas are selected from each BA/biome substratum in proportion to the number of units in that substratum.

When the processing is done, the list of the biomes found in the study area is printed in the *Console* under the buttons, as well as the sampled validation areas. And two or three layers are added to the *Map*:

1) ***MCD64A1*** or ***FireCCI51***: the burned areas according to the selected product between ***date_pre*** and ***date_post***.
2) ***Temporal criterion***: the sampling units filtered by the temporal criterion, if this was applied; otherwise, this layer is not added to the *Map*.
3) ***Validation Areas***: the resulting validation areas sampled in this process.

The tool may have sampled fewer validation areas than specified by the ***numberVA*** variable, due to an insufficient amount of sampling units in a BA/biome stratum. In this case the user should increase the number of VA to sample, and re-run the process.

To export the result to the user's Google Drive account the button ***Export results*** must be used.

If the study area is too large or the period of the BA product too long, the '*User memory limit*' may exceed after pressing the ***Show results*** button. In this case it is more preferable to use directly the button ***Export results***, without displaying the results in the *Map*, since GEE grants more memory capacity to processes that are exported but not shown in the interface. Not applying the temporal criterion also helps making the process faster.

The exported file has the following name:

BAMT_VA_*ID_SENSOR_DATE1-DATE2_DIM*km.shp

where:

- **ID**: the identifier defined by the user.
- **SENSOR**: *S2MSI* or *Lndst*, depending on the selected dataset, corresponding to Sentinel-2 MSI and Landsat respectively.
- **DATE1**: the beginning of the BA product's period (***date_pre***), in *YYYYMMDD* format.
- **DATE2**: the end of the BA product's period (***date_post***), in *YYYYMMDD* format.
- **DIM**: the width and height of the validation areas, which are squares in the centres of Landsat scenes or S2 tiles.

Every validation area has these attributes below:

- ***BIOME***: the predominant Olson biome found in the area.
- ***BA***: the total burned surface in km^2 in the area between ***DATE1*** and ***DATE2*** according to the MCD64A1 or FireCCI51 product.
- ***BAstratum***: the stratum this validation area belongs to (high and low BA strata).
- ***DATE1***: the beginning of the validation area's period, in *YYYYMMDD* format.
- ***DATE2***: the end of the validation area's period, in *YYYYMMDD* format.
- ***DAYS***: the length of the period in days, from ***DATE1*** to ***DATE2***.

There will be two more attributes, which depend on the chosen dataset. If Landsat was chosen:

- ***PATH***: the path of the Landsat scene the sampling unit was based on.
- ***ROW***: the row of the Landsat scene the sampling unit was based on.

Or if Sentinel-2 was chosen:

- ***TILE***: the code of the S2 tile the sampling unit was based on.
- ***ORBIT***: the codes of orbits whose swaths cover at least 95% of the validation area.

4 VA Dates tool

https://code.earthengine.google.com/df4719fc18017e211ebe4baaff2f5549

After sampling the validation areas, the next step is to create reference data, but for that the exact dates where images are available must be known. This tool simply tells the user the available dates in each validation area.

The tool works with an interface, which is easier to handle; this interface will appear after pressing the button ***Run***. The parameters that must be defined are divided in four sections:

1) ***Dataset***: the data must be chosen from a list that contains all the possible values (the same as in the previous tools).
2) ***Region***: the size of the validation area (10, 20, 30, 50 or 100 km), and the path and row (if a Landsat dataset was chosen) or the tile code (if the Sentinel-2 dataset was chosen).
3) ***Dates***: the beginning and end of the validation area's period.
4) ***Cloud coverage***: images with a cloud coverage higher than this value will not be displayed.

The dataset, the size of the validation area and the cloud coverage should be the same as in the previous VA tool. The path/row or tile and the dates will depend on the validation area.

After defining all these parameters, the button ***Load and display*** can be pressed, and all the available images in the validation area for the defined period will be added in the *Map*, all of them with a cloud coverage lower than the defined threshold; the date of each image can be seen in the *Layers* list in the *YYYYMMDD* format (Figure 11). Please keep in mind that the cloud coverage value in the image's metadata is used, so images from some dates may contain too many clouds for the filtering threshold.

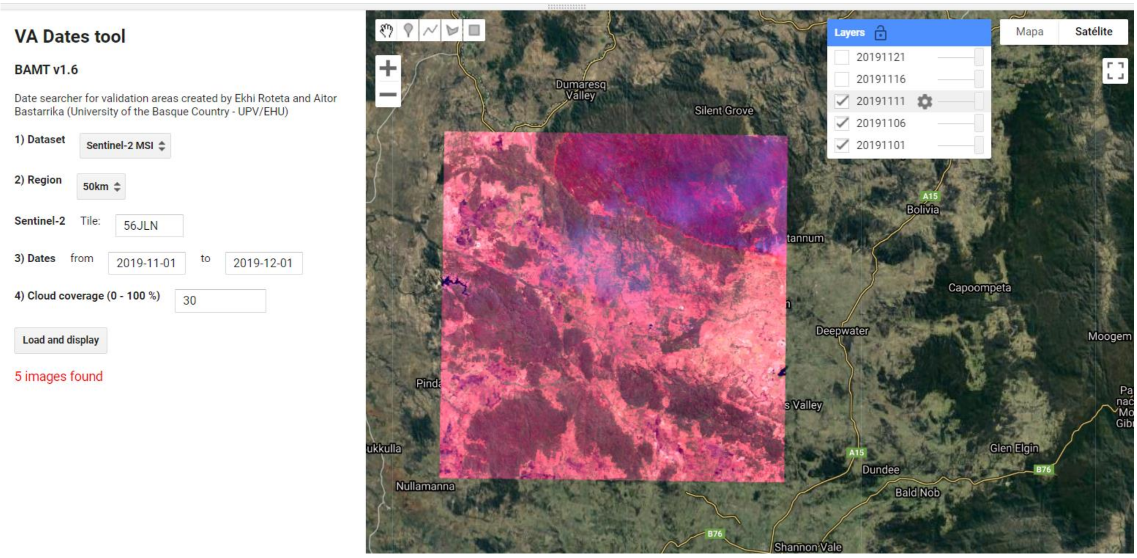


Figure 11. Example image of the *VA Dates* tool; input parameters can be seen in the interface on the left, and the resulting images in the map.

5 RP tool

https://code.earthengine.google.com/61a5ebd4ecd32efe00c2392cc6e81d3f

The aim of this tool is a high-quality burned area detection between two different images for assessment purposes, via a supervised classification and within a small region; the images are selected from pre-fire and post-fire single dates defined by the user, instead of using temporal composites.

The process, practically identical to that of the *BA* Cartography tool, consists on training a Random Forest classifier, using various spectral bands and indices from the post-fire image and from a multitemporal difference image. This classifier returns an image with a probability value from 0 % (unburned) to 100 % (burned) for every pixel. A two phase algorithm is applied upon this image, first identifying burned seeds (pixels with a very strong burned signal) and then extending the burned areas around these seeds. The burned areas can be exported in the ESRI Shapefile format, with only two possible values for the unique attribute: *BURNED* or *UNOBSERVED*.

5.1 Initial parameters

In the first step of the burned area detection, the user must define some initial parameters, which will fix the dates, the geographic region and the dataset to be used. All these variables are defined at the beginning of the script, between lines 6 to 32.

5.1.1 Dates

The burned areas are detected comparing two different images corresponding to the pre-fire and the post-fire dates:

- ***date_1***: the pre-fire date.
- ***date_2***: the post-fire date.

All three dates must belong to the **String** data type and be written in the 'YYYY-MM-DD' format. The user can use the *VA Dates* tool to know which dates are available.

5.1.2 Region

There are three different options for the ***region_type*** variable: '*Landsat*', '*Sentinel*' or '*manual*'.

Landsat

The region is a square in the centre of a Landsat scene. The scene is selected by the ***path*** and ***row*** variables, both in a **Number** (and not String) data type; the dimension of the region is defined by the ***region_dimension*** variable, which is the width and height of the square in km; only values of *10*, *20*, *30*, *50* or *100* km are allowed for this dimension. Only Landsat data are used in this option, from Landsat-4 on (Landsat-4 TM, Landsat-5 TM, Landsat-7 ETM+ and Landsat-8 OLI). As the Landsat-4 satellite was launched in July 1982, there is no available image before that date. Burned areas are processed at 30 m spatial resolution.

Sentinel

Similar to the *Landsat* region type, this region is a square in the centre of a Sentinel-2 tile, selected by the ***tile*** variable in a **String** data type. The ***region_dimension*** variable defines the width and height of the square in km, with allowed values of *10*, *20*, *30*, *50* and *100*. Only Sentinel-2 MSI data are used in this option, combining both Sentinel-2A and 2B satellites when available; as the first satellite (S2A) was launched in June 2015, there is no available image before that date. Burned areas can be processed at both 20 and 10 m spatial resolution, defined by the ***resolution*** variable.

manual

This option is recommended when the user needs to detect burned areas in an area not located in the centre of a Landsat scene or a Sentinel-2 tile. In this case the region is defined manually as a rectangle; there is a *Geometry Input* layer called ***region_manual*** for this purpose. Any preexisting polygon should be removed from this layer before defining a new region.

When this manual region is selected, the user must specify which dataset will be used, Landsat or Sentinel-2. If Landsat data are selected, the burned areas will later be detected at 30 m; otherwise, with Sentinel-2 data, at 20 or 10 m depending on the defined value for the ***resolution*** variable.

5.2 First layers

Once all the previous variables are defined, the user can press the button ***Run*** to execute the script.

At this moment, the pre-fire and post-fire images are taken from the dates defined by the user, selecting six spectral bands from each image (Table 1): the three visible bands (blue, green and red), the near infrared (NIR), and both short wavelength infrareds (short and long SWIRs). Aside from those 6 bands, 3 spectral indices based on normalized differences are computed for both images as well:

- Normalized Difference Vegetation Index (NDVI)

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

- Normalized Burn Ratio (NBR)

$$NBR = \frac{LongSWIR - NIR}{LongSWIR + NIR}$$

- Normalized Burn Ratio 2 (NBR2)

$$NBR2 = \frac{LongSWIR - ShortSWIR}{LongSWIR + ShortSWIR}$$

At the same time, several layers are shown in the map, which can be managed in the *Layer manager*:

- ***Pre-fire***: a colour composition of the pre-fire image, with the Long SWIR, NIR and Red bands corresponding to the RGB colours.
- ***Post-fire***: a colour composition of the post-fire image, with the Long SWIR, NIR and Red bands corresponding to the RGB colours.
- ***Difference***: a simple difference between both colour compositions, $image_{post\text{-}fire}$ - $image_{pre\text{-}fire}$.
- ***MCD64A1***: areas burned between the two dates according to the MCD64A1 c6 product, at 500 m. As this product is only available from November 2000 on, this layer is not shown in the map for earlier dates.

Both the pre-fire and the post-fire images are masked where clouds and cloud shadows could be detected. When Landsat images are used, the *pixel_qa* band is used for this purpose. With Sentinel-2 images, the *QA60* band from the L1C product is used, except when the L2A product for the same date is available; in that case, the Scene Classification or SCL is used to mask these areas.

Two new buttons are printed in the *Console* as well:

- ***Zoom to region***: a general zoom to the region.

- ***No BA observed. Export results anyway***: this button exports the results between the two dates for this tile, when no BA is observed and the Random Forest classifier cannot be trained. Three files are exported: the pre-fire and post-fire images (the colour compositions shown in the map) and a shapefile, which will only contain polygons for unobserved areas.

  If BA are observed, please do not press this button and define training polygons instead. For more information about these results, please see section 5.4.

5.3 BA detection

Once some burned and unburned training polygons are defined using the available ***burned*** and ***unburned*** layers as *Geometry Imports* (Figure 12), burned areas can be detected for the first time. It is recommended to define polygons instead of rectangles, adjusting their shapes to burned areas, and at least one training polygon is required for each class; otherwise a new polygon will be asked to be defined.

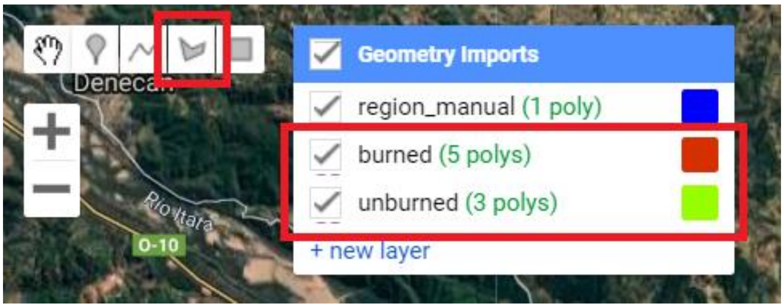


Figure 12. The layers to be used to define training polygons.

After pressing the ***Run*** button, burned areas are detected based on the training polygons. These areas are classified by a Random Forest classifier with 100 decision trees and nodes with a minimum of 10 leaves; the classifier is trained by all pixels contained in the training polygons. A total of 18 variables are introduced, the original 6 bands (blue, green, red, NIR and both SWIRs) and 3 spectral indices (NDVI, NBR and NBR2), each one of them twice: the post-fire value, and the difference between the pre- and post-fire values.

With S2 data, the user can select to process BA either at 20 or 10 m; the only difference is the NIR band being B8A or B8, respectively. In the first case, the original blue, green and red bands have a spatial resolution of 10 m, but 20 m for the NIR (B8A) and both SWIR bands, so BA are processed at 20m (Figure 13a and c). In the second case, the visible bands, the NIR (B8) and the NDVI index are at 10 m, and both SWIR bands and the NBR2 spectral index at 20 m. The resolution of the spectral index NBR is located halfway, as GEE can combine bands at different resolutions: NIR at 10 m and Long SWIR at 20 m, giving the impression the NBR was computed with two bands at 10 m (Figure 13b and d). Therefore, when the option at 10 m is selected, the B8 band is chosen as NIR, and BA are processed at 10 m, even though not every band/index has this resolution.

a) 
b) 

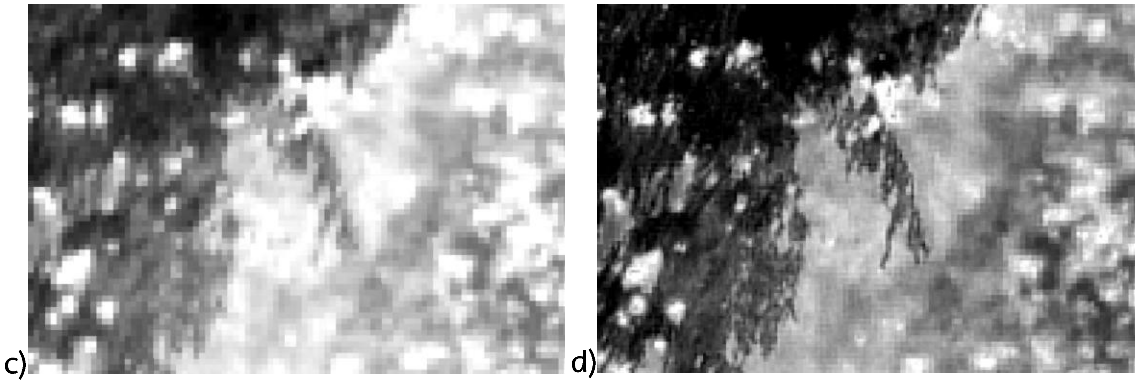


Figure 13. Sample area in S2 tile 36NVP, in South Sudan. a) NIR band at 20 m (B8A); b) NIR band at 10 m (B8); c) NBR index at 20 m (from B8A and B12); and d) NBR index at 10 m (from B8 and B12).

The result returned by the classifier is a probability image with values from 0 % (unburned) to 100 % (burned). Burned seeds are extracted from this image, representing pixels with the strongest burned signal; the threshold used here is the minimum among the mean burned probabilities in every burned training polygon. Two new layers are now added to the *Map* (Figure 14):

- ***BA***: the probability image. To make easier its visualisation, a threshold of 50 % is applied to this image before being displayed, so that unburned pixels are transparent and the image at the bottom can be seen. Burned pixels are displayed with a colour palette from white (probability values close to 50 %) to blue (100 % probability of burned).
- ***Seeds***: the seeds extracted from the previous probability image in a red colour.

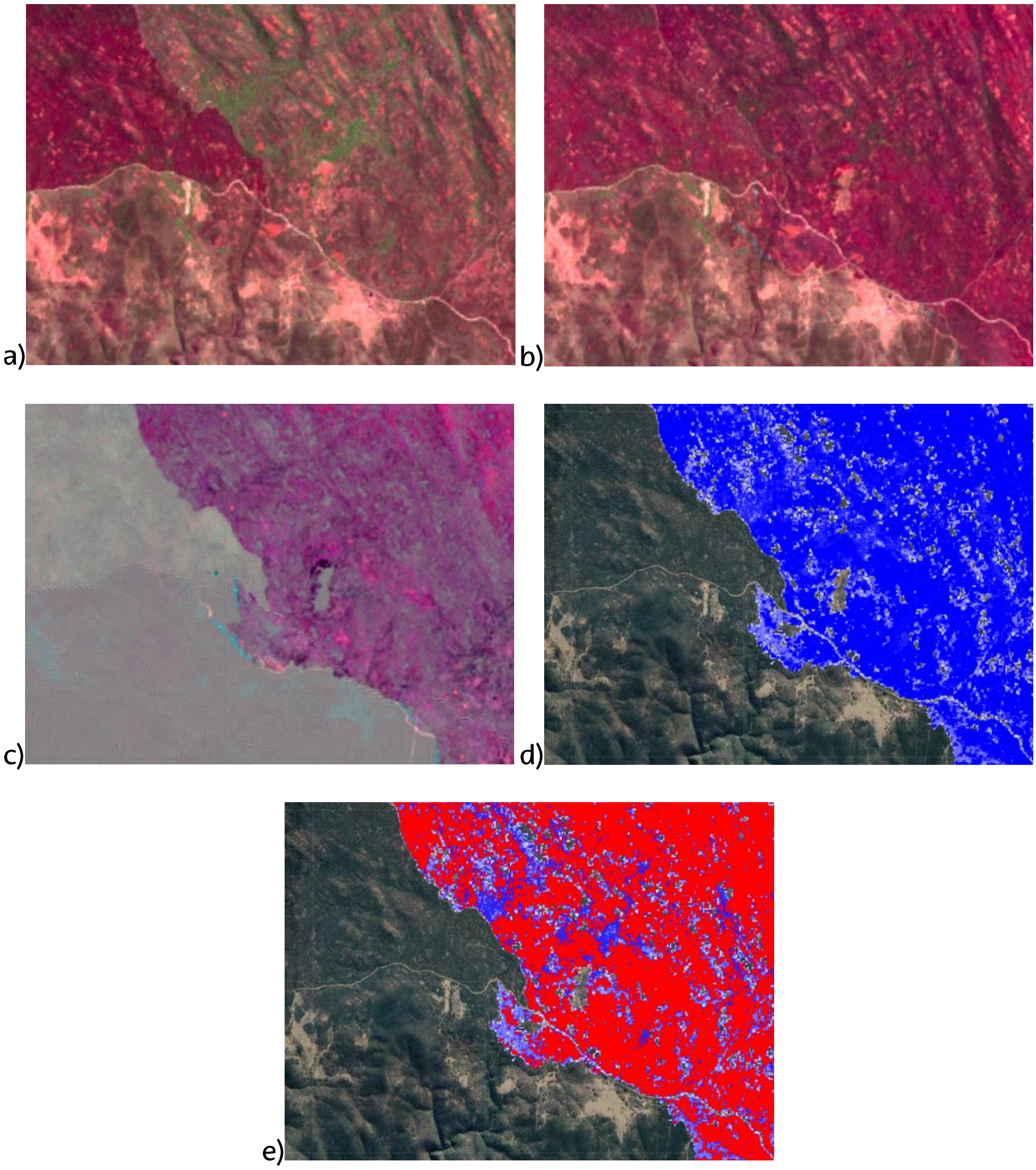


Figure 14. Sample area in S2 tile 56JLN, in Australia. a) pre-fire image from 6th November 2019, b) post-fire image from 16th November 2019, c) difference image between both dates, d) probability of burn image with the Google Satellite image in the background, and e) the seeds in red shown on the previous image.

The user can now modify or define new training polygons until the desired results are obtained, pressing the ***Run*** button at each iteration to update the BA. Not all pixels with a probability higher than 50 % are exported in the end: burned areas are expanded from seeds outwards up to the 50 % threshold (section 5.4). Thus, the user should keep in mind that burned areas in layer ***BA*** will not be exported if they do not contain any seed.

5.4 Exporting results

When the desired result is finally reached, it can be exported to the user's Google Drive account by the ***Export BA*** button in the *Console*. A total of 4 different files can be downloaded: the 1) pre-fire and 2) post-fire images with the colour compositions shown in the map, 3) the probability of burn image (from 0 to 100 %), and 4) the shapefile with polygons. These polygons have only one attribute, with a *BURNED* or *UNOBSERVED* label; observed and unburned areas are not included in the shapefile. Except for the probability of burn image, the files are identical to those mentioned at the end of section 5.2.

The files have the following names:

1) **BAMT_RP_*ID_SENSOR*_TILE-*TILEID_DATE1*_RGB.tif**
2) **BAMT_RP_*ID_SENSOR*_TILE-*TILEID_DATE2*_RGB.tif**
3) **BAMT_RP_*ID_SENSOR*_TILE-*TILEID_DATE1_DATE2*_TIF.tif**
4) **BAMT_RP_*ID_SENSOR*_TILE-*TILEID_DATE1_DATE2*_SHP.shp**

where:

- **ID**: the identifier defined by the user.
- **SENSOR**: *S2MSI* or *Lndst*, depending on the used dataset, corresponding to Sentinel-2 MSI and Landsat respectively.
- **TILEID**: the ID of the tile depends on the selected value for the *region_type* variable:

- Landsat: ***DIM*km-*PPPRRR***, where ***DIM*** stands for the width and height of the square in the centre of the Landsat scene, and ***PPP*** and ***RRR*** stand for the path and row respectively, each with three digits. E.g. '50km-090080' for a square 50 km wide and high in the centre of the Landsat scene with path 90 and row 80.
- Sentinel: ***DIM*km-*TTTTT***, where ***DIM*** stands for the width and height of the square in the centre of the Sentinel tile, with ***TTTTT*** being the tile's code. E.g. '50km-56JLN' for a square 50 km wide and high in the centre of the S2 56JLN tile.
- Manual: **Mnl-*LAT*-*LON***, where the **LAT** and **LON** represent the latitude and longitude of the centre of the region defined by the user, with one decimal and the Northern/Southern and Western/Eastern hemisphere suffixes. E.g. 'Mnl-29.4S-151.5E'.

- **DATE1**: the pre-fire date, in *YYYYMMDD* format.
- **DATE2**: the post-fire date, in *YYYYMMDD* format.

There may be some slight differences between the burned areas displayed in the GEE API map and those exported in shapefiles to Google Drive. A two-phase algorithm is applied on the RF probability image before vectorizing it, with the aim to reduce noise. In the first phase burned seeds are extracted from the probability image, as already explained. In a second phase, the burned areas are expanded from these seeds outwards up to a 50 % threshold. These grown burned areas are then polygonized and exported.

Finally, once the BA detected and all the necessary data exported, it is important not to forget to delete some polygons before beginning to detect BA elsewhere.

The *region_manual* layer cannot have more than a rectangle at the same time, so when the option *manual* is selected as region type the previous rectangle should be removed before changing the region. As for burned and unburned training polygons, the tool filters these polygons with the region, so it is not necessary to delete them when changing region. They must be deleted, however, if the dates are changed but not the region, as pixels in training polygons will hardly correspond to the same class.

However, the training polygons can be saved in case the process must be repeated. It is as simple as saving a copy of the script. While the user continues working in the original script, the region, the dates and the training polygons will be kept safe in the copy.

6 Image Viewer tool

https://code.earthengine.google.com/e8ff23518a2ec00c5e2c648c4251c403

This is an extra tool, not related to BA mapping, which serves for the user to view Landsat or Sentinel-2 images from any corner of the world. The tool is very easy to handle, since it works via an interface just as the *VA Dates* tool. The interface appears after pressing the button ***Run***, with these parameters:

1) ***Dataset***:the data must be chosen from a list that contains all the possible options:
   - ***Sentinel-2 MSI L1C***: L1C products of the MSI sensor aboard Sentinel-2A and 2B satellites.
   - ***Sentinel-2 MSI L2A***: L2A products of the MSI sensor aboard Sentinel-2A and 2B satellites.
   - ***Landsat-8 OLI***: OLI sensor aboard the Landsat-8 satellite.
   - ***Landsat-7 ETM+***: ETM+ sensor aboard the Landsat-7 satellite.
   - ***Landsat-5 TM***: TM sensor aboard Landsat-5.
   - ***Landsat-4 TM***: TM sensor aboard Landsat-4.
   - ***Landsat 4-8***: sensors TM, ETM+ and OLI aboard satellites Landsat-4 to 8.
2) ***Region***: if Sentinel-2 data are selected, the user must choose between options ***Sentinel-2 Tile*** and ***Map view***; if some Landsat dataset is selected, between ***Landsat Scene*** and ***Map view***.
   - ***Sentinel-2 Tile***: the images are filtered by the S2 ***Tile*** defined by the user.
   - ***Landsat Scene***: the images are filtered by the Landsat ***Path*** and ***Row*** defined by the user.

There are two layers called ***Sentinel-2 tiles*** and ***Landsat scenes*** available in the map for the user to consult, in case the ID or the path/row of the desired S2 tile or Landsat scene are unknown. This information will appear in the *Inspector* tab after clicking on them in the *Map*.

- ***Map view***: the displayed images will be those covering the area of the current map view.

3) ***Dates***: the beginning and end of the period to display.
4) ***Cloud coverage***: images with a cloud coverage higher than this value will not be displayed. If ***Sentinel-2 Tile*** or ***Landsat Scene*** was selected as region, images are filtered with the cloudiness value in the metadata. Otherwise (***Map view***), the cloud coverage is computed for every image in the *Map view* area; for large areas or long periods, this may slow down or even crash the process with a message of '*Too many concurrent aggregations*' printed in the *Console*.
5) ***Visualization parameters***: here the colour composition is formed by selecting the bands for each RGB colours, from a list with 6 bands (Blue, Green, Red, NIR, Short SWIR or SWIR1, and Long SWIR or SWIR2), and 4 spectral indices (NDVI, NBR, NBR2 and MIRBI). All bands can be stretched between minimum and maximum values defined on the right.

   Four predefined compositions are already available for the user: ***Natural colour*** (Red-Green-Blue), ***Modified natural colour***, ***NIR-Red-Green*** and ***SWIR2-NIR-Red***. The ***Modified natural colour*** composition tries to remove the effect of the atmospheric dispersion to the ***Natural colour***, so it is recommended for the ***Sentinel-2 MSI L1C*** dataset, which contains Top-Of-Atmosphere reflectances.

Finally, a temporal composite can be created by checking the checkbox right to ***Composite***, thus maximazing (***Max***) or minimazing (***Min***) the selected band or spectral index. If ***Mask*** is selected instead of ***No mask***, clouds and cloud shadows are masked before maximazing or minimazing.

After defining all these parameters, the button ***Load and display*** can be pressed, and all the available images in the selected region for the defined period will be displayed in the *Map*, all of them with a cloud coverage lower than the defined threshold; the date of each image can be seen in the *Layers* list in the *YYYYMMDD* format (Figure 15).

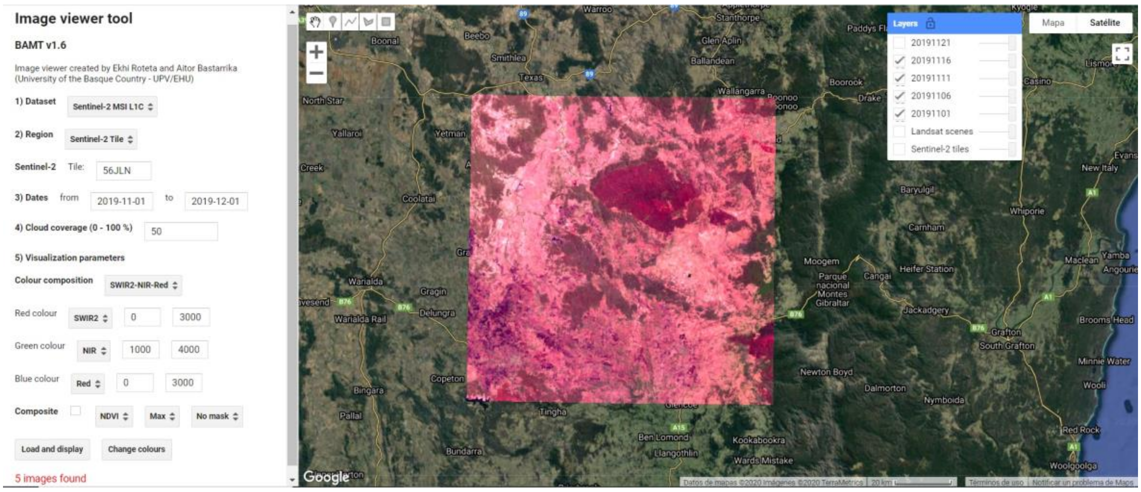


Figure 15. Example image of the *Image viewer* tool; input parameters can be seen in the interface on the left, and the resulting images in the map.

A message telling the number of found images is printed below the buttons; if no image was found in the area for the defined period, the message is '*No image found. Please change parameters*' instead.

Once the images have been displayed, a new button is available: ***Change colours***. This button is recommended whenever the user wants to change ***Visualization parameters***, but not the dataset, region, dates and cloud coverage; since the images are already loaded, this button just changes the visualization parameters, without loading images again. This way the process is faster, especially if ***Map view*** was selected as region.

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