ESA Climate Change Initiative – Fire_cci
D3.3.3 Product User Guide - MODIS (PUG)

Project Name	ECV Fire Disturbance: Fire_cci Phase 2
Contract Nº	4000115006/15/I-NB
Issue Date	16/05/2018
Version	1.1
Author	M. Lucrecia Pettinari, Emilio Chuvieco
Document Ref.	Fire_cci_D3.3.3_PUG-MODIS_v1.1
Document type	Public

To be cited as: M.L. Pettinari, E. Chuvieco (2018) ESA CCI ECV Fire Disturbance: D3.3.3 Product User Guide - MODIS, version 1.1. Available at: http://www.esa-fire-cci.org/documents

Project Partners

Prime Contractor/ Scientific Lead & Project Management	UAH – University of Alcala (Spain)
Earth Observation Team	UAH – University of Alcala (Spain) EHU – University of the Basque Country (Spain) UL – University of Leicester (United Kingdom) UCL – University College London (United Kingdom) ISA – School of Agriculture, University of Lisbon (Portugal)
System Engineering	BC – Brockmann Consult (Germany)
Climate Research Group	MPIC – Max Planck Institute for Chemistry (Germany) IRD - Research Institute for Development (France) LSCE - Climate and Environmental Sciences Laboratory (France) VUA - Stichting VU-VUmc (Netherlands)

Distribution

Affiliation	Name	Address	Copies
ESA	Stephen Plummer (ESA)	stephen.plummer@esa.int	electronic copy
Project Team	Emilio Chuvieco (UAH)	emilio.chuvieco@uah.es	electronic copy
	M. Lucrecia Pettinari (UAH)	mlucrecia.pettinari@uah.es	
	Joshua Lizundia (UAH)	joshua.lizundia@uah.es	
	Gonzalo Otón (UAH)	gonzalo.oton@uah.es	
	Mihai Tanase (UAH)	mihai.tanase@uah.es	
	Miguel Ángel Belenguer (UAH)	miguel.belenguer@uah.es	
	Aitor Bastarrika (EHU)	aitor.bastarrika@ehu.es	
	Ekhi Roteta (EHU)	ekhi.roteta@gmail.com	
	Kevin Tansey (UL)	kjt7@leicester.ac.uk	
	Marc Padilla Parellada (UL)	mp489@leicester.ac.uk	
	James Wheeler (UL)	jemw3@leicester.ac.uk	
	Philip Lewis (UCL)	ucfalew@ucl.ac.uk	
	José Gómez Dans (UCL)	j.gomez-dans@ucl.ac.uk	
	James Brennan (UCL)	james.brennan.11@ucl.ac.uk	
	Jose Miguel Pereira (ISA)	jmocpereira@gmail.com	
	Duarte Oom (ISA)	duarte.oom@gmail.com	
	Manuel Campagnolo (ISA)	mlc@isa.ulisboa.pt	
	Thomas Storm (BC)	thomas.storm@brockmann-consult.de	
	Johannes Kaiser (MPIC)	j.kaiser@mpic.de	
	Angelika Heil (MPIC)	a.heil@mpic.de	
	Florent Mouillot (IRD)	florent.mouillot@cefe.cnrs.fr	
	M. Vanesa Moreno (IRD)	mariavanesa.morenodominguez@cefe...	
	Philippe Ciais (LSCE)	philippe.ciais@lsce.ipsl.fr	
	Chao Yue (LSCE)	chaoyuejoy@gmail.com	
	Pierre Laurent (LSCE)	pierre.laurent@lsce.ipsl.fr	
	Guido van der Werf (VUA)	guido.vander.werf@vu.nl	
	Ioannis Bistinas (VUA)	i.bistinas@vu.nl	

Summary

This document is the version 1.1 of the Product User Guide for the MODIS Fire_cci v5.0 product (FireCCI50). It provides practical information about the use of the Fire_cci global burned area products based on the MODIS sensor.

	Affiliation/Function	Name	Date
Prepared	UAH - Project Manager UAH - Science Leader	M. Lucrecia Pettinari Emilio Chuvieco	16/05/2018
Reviewed	UAH – Project Manager	Lucrecia Pettinari	16/05/2018
Authorized	UAH - Science Leader	Emilio Chuvieco	16/05/2018
Accepted	ESA - Technical Officer	Stephen Plummer	16/05/2018

This document is not signed. It is provided as an electronic copy.

Document Status Sheet

Issue	Date	Details
1.0	30/01/2018	First Issue
1.1	16/05/2018	Addressing comments of ESA-CCI-FIRE-EOPS-MEM-18-0011

Document Change Record

Issue	Date	Request	Location	Details
1	16/05/2018	UAH	All document	Inclusion of product acronym.
2	16/05/2018	ESA	Section 1.2	Added explanation on how the 1000 m data was resampled.
3	16/05/2018	ESA	Section 2.4.2	Added clarification.
4	16/05/2018	ESA	Section 2.4.3	Added clarification of "not burned" meaning in the table.
5	16/05/2018	ESA	Section 2.6	Added table foot to Table 1.
6	16/05/2018	UAH	Section 2.8	Fixed an error in the years assigned to the different LC_cci epochs.
7	16/05/2018	ESA	Section 3.4.4	Minor modifications in the recommendation on product use.

Table of Contents

List of Tables

List of Figures

1. General overview

The ESA CCI Programme comprises the generation and provision of Essential Climate Variables (ECV) on global scale based on long-term satellite data time series. "Fire Disturbance" is deemed as one of these ECVs and is tackled through the Fire_cci project. Burned area (BA) is considered as the primary variable for the Fire Disturbance ECV.

This document contains practical information on how to use the MODIS Fire_cci BA v5.0 products (also called FireCCI50 for short), which are based on the Moderate Resolution Imaging Spectroradiometer (MODIS) on board the Terra satellite.

1.1. Introduction

The MODIS Fire_cci version 5.0 products (FireCCI50) comprise maps of global burned area developed and tailored for use by climate, vegetation and atmospheric modellers, as well as by fire researchers or fire managers interested in historical burned patterns. These products complement and extend the temporal range of the previous BA product developed by the Fire_cci product: MERIS Fire_cci v4.1 (Chuvieco et al. 2016), which comprised the 2005-2011 period.

The Fire_cci project produces two burned area products available at different spatial resolutions, the PIXEL product and the GRID product, which is derived from the pixel one.

1.2. Available data and key features of the MODIS images

The main input for this BA Fire_cci product are the MOD09GQ Collection 6 images, acquired by the Terra satellite, which offer daily surface reflectance information in the RED and near infrared (NIR) bands of the MODIS sensor at 250 m spatial resolution. Complementary to the surface reflectance product, the daily MOD09GA Collection 6 product was also used to extract information on the quality of the data (quality flags). The resolution of this latter product is 1000 m, and was resampled to 250 m. Active fire information was also used, extracted from the MCD14ML Collection 6 product (Giglio 2015), also with 1000 m resolution. In this case, the hotspots were assigned to the 250 m MOD09GQ pixel inside each MCD14ML pixel that had the lowest NIR value.

The unit of analysis of the MODIS products is the standard tile (1200x1200 km) in sinusoidal coordinates in which they are delivered (Vermote et al. 2015). All other input data has been reprojected to this coordinate system, if necessary, prior to processing. However, the final products have been reprojected to geographical coordinates to keep consistency with other CCI products.

1.3. BA algorithm

The BA algorithm used for producing the final Fire_cci BA product is a hybrid approach, combining information on active fires and temporal changes in reflectance. The algorithm is divided in two phases: in the first one the most clearly burned pixels are discriminated as "seed" pixels, while in the second one, a contextual procedure is run to improve the detection of the whole burned patch. In both phases, tile statistics are computed for each monthly period, to adapt the discrimination thresholds to spatial and temporal variations of burning conditions. The algorithm is described in the Algorithm Theoretical Basis Document (ATBD, Lizundia et al. 2018).

2. Pixel BA product

The pixel BA product is a GeoTIFF file with four layers indicating the date of detection (Figure 2.1), the confidence level and the land cover in the pixel detected as burned (see Section 2.3 for further detail).
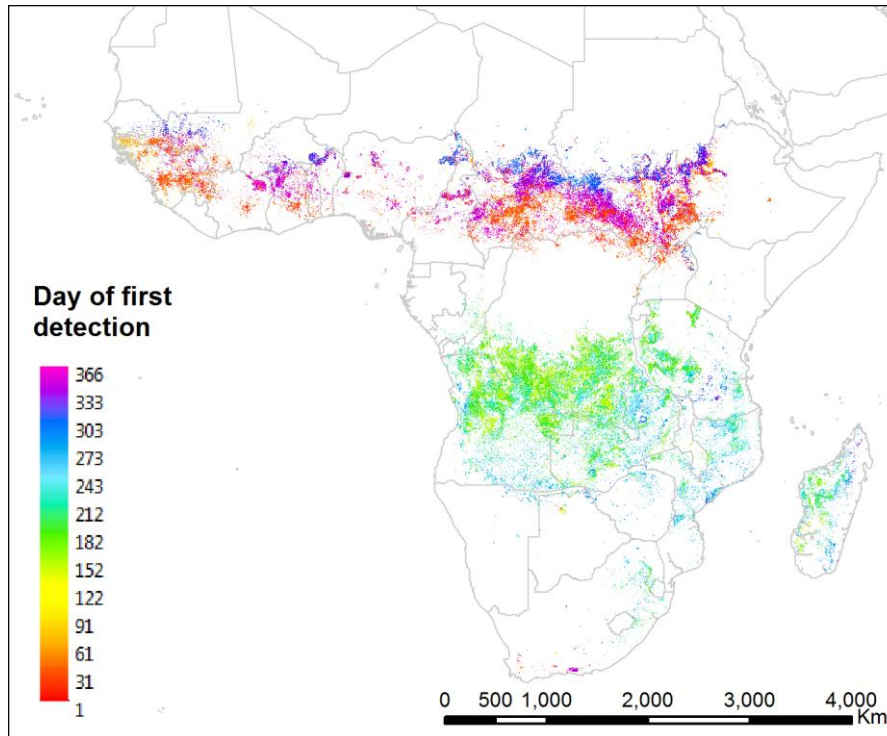
Figure 2.1: Day of detection for Area 5 (Sub-Saharan Africa) for the year 2016, derived from the pixel product.

2.1. Temporal compositing

The pixel products are released as monthly composites as they can tackle those pixels that burn more than once during a calendar year. This may occur in the North Tropical areas, where the dry season commonly occurs between December and February.

2.2. Spatial Resolution

The Spatial resolution of this BA product is 0.0022457331 degrees (approximately 250 m at the Equator), which is the original resolution of MODIS Red and NIR bands.

2.3. Product projection system

The Coordinate Reference System (CRS) used for the global BA products is a geographic coordinate system (GCS) based on the World Geodetic System 84 (WGS84) reference ellipsoid and using a Plate Carrée projection with geographical coordinates of equal pixel size. It is the same reference system used by the Land Cover CCI product. The coordinates are specified in decimal degrees. Information on product projection, ellipsoid and pixel size is included in the GeoTIFF file header, so every pixel in the file can be geographically referenced without the need of adding specific pixel indicators of geographical position.

2.4. Pixel attributes

The following sub-sections describe each of the layers of the pixel product, including the name of the attributes in the GeoTIFF file, the units of the attributes and the data type, and some information useful for the correct use of the product.

They also include examples of the pixel product layers.

2.4.1. Layer 1: Date of the first detection

Layer	Attribute	Units	Data Type	Notes
1	Date of the first detection (JD)	Day of the year, from 1 to 365 (or 366)	Integer	Possible values: • 0 (zero): when the pixel is not burned. • 1 to 366: day of the first detection when the pixel is burned. • -1: when the pixel is not observed in the month. • -2: used for pixels that are not burnable: continuous water, bare land, urban, permanent ice-snow.

This layer corresponds to the day that the fire was first detected, also commonly called Julian Day. When the pixel is characterized as burned, it is assumed that the complete pixel was burned, as for all burned area products.

The date of the burned pixel may not be coincident with the actual burning date, but most probably taken from one to several days afterwards, depending on image availability and cloud coverage. For areas with low cloud coverage, the detected date of burn should be very close to the actual date of burn, while for areas with high cloud coverage the date may be from several days or even weeks after the fire is over.

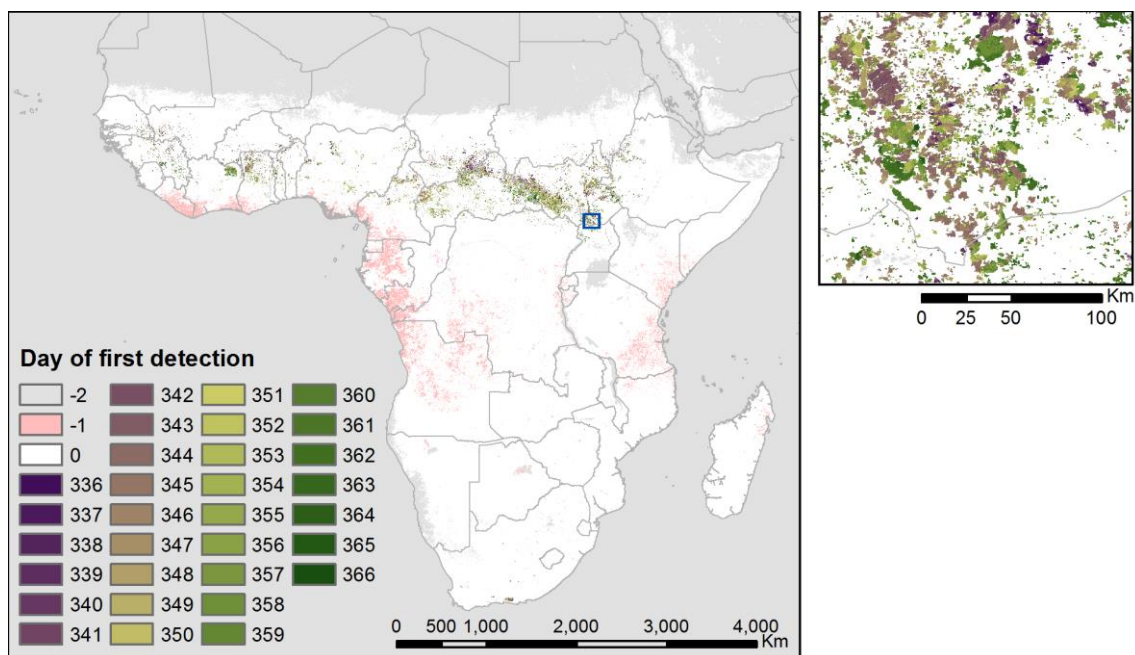An example of this layer corresponding to December 2016 for Area 5 is shown in Figure 2.2.

Figure 2.2: Example of the Date of the first detection layer for the 20161201-ESACCI-L3S_FIRE-BA-MODIS-AREA_5-fv05.0.tif file.

2.4.2. Layer 2: Confidence level

Layer	Attribute	Units	Data Type	Notes
2	Confidence level (CL)	0 to 100	Byte	Probability of detecting a pixel as burned. Possible values: - 0 (zero): when the pixel is not observed in the month, or it is not burnable. - 1 to 100: Probability values. The closer to 100, the higher the confidence that the pixel is actually burned. This value expresses the uncertainty of the detection for all pixels, even if they are unburned.

The confidence level is the probability that the pixel is actually burned. A pixel with a confidence level of 80 means that it is burned with a probability of 80%, which implies that the input data and the algorithm result in a fairly high belief of the pixel being burned. A low value (for instance, 5) would indicate a strong belief of the pixel not being burned. These values can also be called "per pixel" uncertainty (p_b). p_b was modelled from the uncertainty of the different input variables used in the MODIS BA algorithm (Lizundia et al. 2018). It should be noted that this uncertainty is just a description of how much one can trust the interpretation of the burned/unburned state of a pixel given the uncertainty of the data, the choices done in modelling, etc. (Lewis et al. 2017) It does not give an indication about whether the estimates of BA are close to the truth, as that is really the role of validation. An example of this layer corresponding to December 2016 for Area 5 is shown in Figure 2.3. All pixels with a burnable land cover include a confidence level, both if they are classified as burned or as not burned.
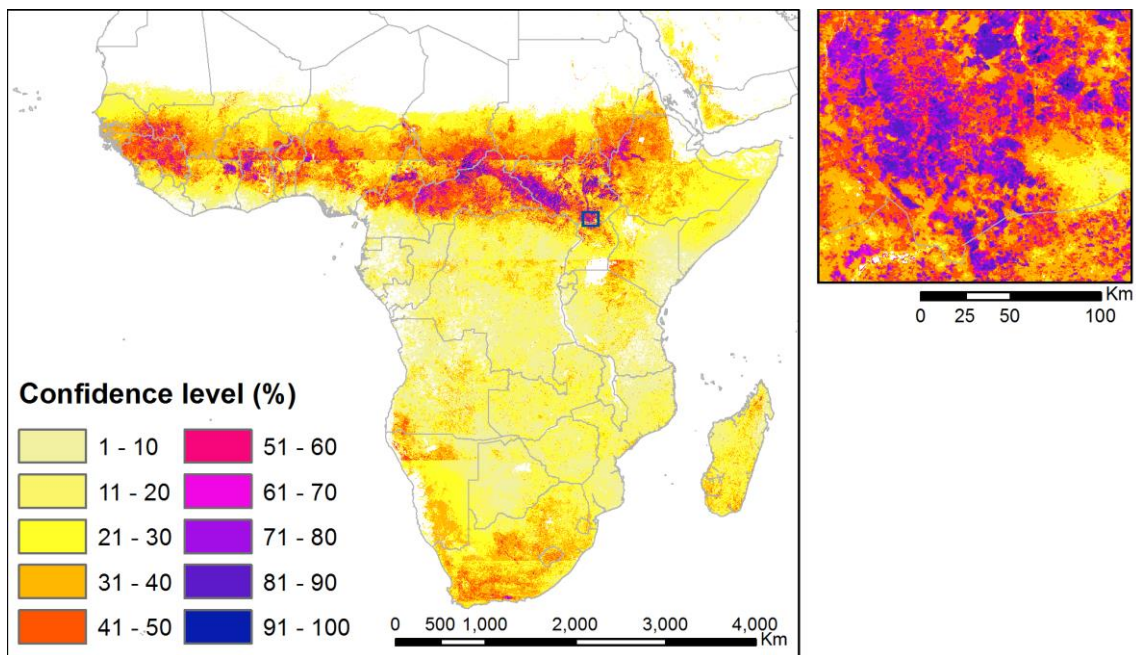

Figure 2.3: Example of the Confidence Level layer for the 20161201-ESACCI-L3S_FIRE-BA-MODIS-AREA_5-fv05.0.tif file.

2.4.3. Layer 3: Land cover of burned pixels

Layer	Attribute	Units	Data Type	Notes
3	Land cover of burned pixels (LC)	0 to N	Byte	Possible values: • 0 (zero): when the pixel is not burned in the month, either because it was observed and not classified as burned, or because it is non burnable or was not observed. • 10 to 180: land cover code when the pixel is burned (codes listed in Annex 1). Land cover of the pixel detected as burned, extracted from the Land Cover CCI maps (see section 2.8).

It is assumed that there is only one land cover within the pixel, as in most land cover maps. This is a reasonable estimation for homogenous land cover areas, but it may imply errors for heterogeneous landscapes. The basic land cover map is the CCI Land Cover map (see Section 2.8). Obviously, errors included in this map also affect the information contained in the BA product and hence the calculation of emissions using land cover based emissions factors would be affected. The resolution of the land cover and BA products is the same, as the land cover was resampled from its original spatial resolution (approx. 300 m at the Equator) to the resolution of the pixel product.

An example of this layer corresponding to December 2016 for Area 5 is shown in Figure 2.4.
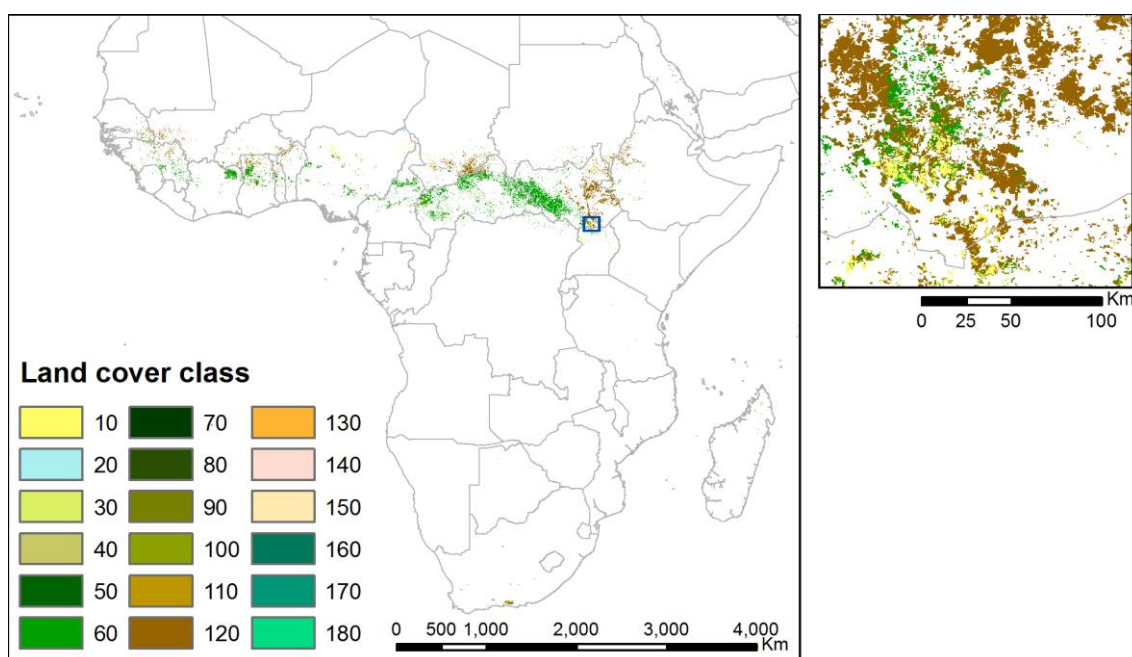

Figure 2.4: Example of the Land Cover layer for the 20161201-ESACCI-L3S_FIRE-BA-MODIS-AREA_5-fv05.0.tif file. The description of the land cover categories is in Annex 1.

2.5. File formats

The product is delivered in GeoTIFF format, with each layer as an individual file, and together compressed into tar.gz files to reduce downloading file sizes.

2.6. Geographical subsets

The BA product is distributed in continental tiles, following a similar approach to other international projects. All subsets are non-overlapping regions. They cover mostly continental tiles, excluding areas that do not burn or are very small and surrounded by large proportions of water. Figure 2.5 shows the extent of these tiles, which are referenced in Table 1.

Table 1: Geographical distribution of BA tiles for the pixel product

Areas	Name	Upper left		Lower right	
1	North America	180°W	83°N	50°W	19°N
2	South America	105°W	19°N	34°W	57°S
3	Europe –North Africa	26°W	83°N	53°E	25°N
4	Asia	53°E	83°N	180°E	0°N
5	Sub-Saharan Africa	26°W	25°N	53°E	40°S
6	Australia & New Zealand	95°E	0°N	180°E	53°S

Coordinates correspond to the centres of the border pixels.
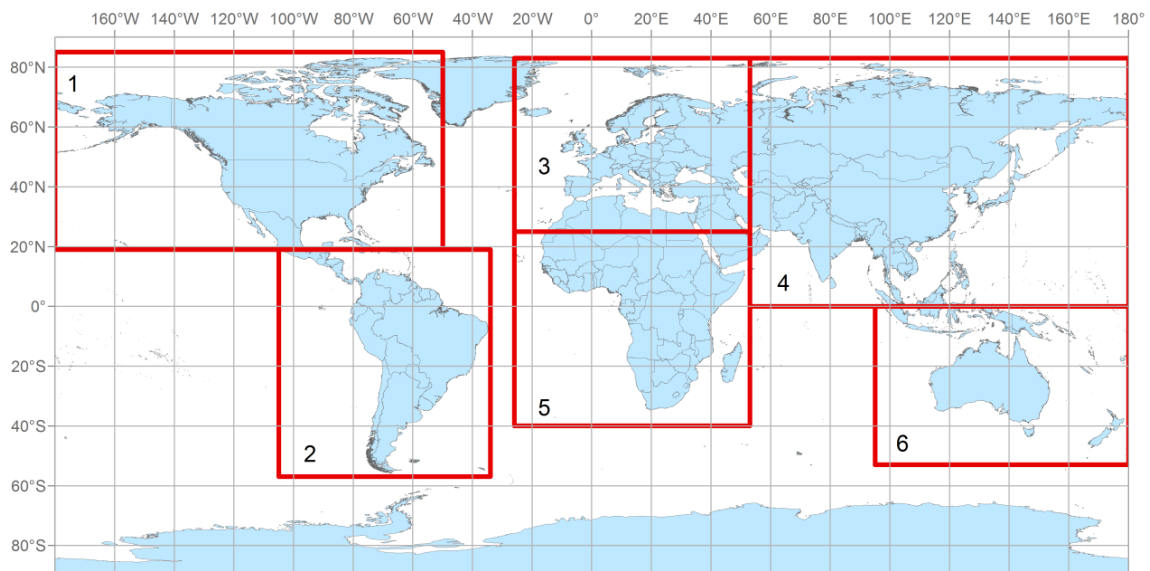
Figure 2.5: Geographical distribution of subsets for the global pixel BA product

2.7. Product file naming conventions

The files for each sensor and month are named as follows:

<Indicative_Date>-ESACCI-L3S_FIRE-BA-<Indicative_sensor>-<Additional_ Segregator>-fv<xx.x>-<Layer>.tiff

<Indicative_Date>

The identifying date for this data set:

Format is YYYYMMDD, where YYYY is the four digit year, MM is the two digit month from 01 to 12 and DD is the two digit day of the month from 01 to 31. For monthly products DD=01.

<Indicative_sensor>

In this version of the product it is MODIS.

<Additional_Segregator>

This is AREA_<TILE_NUMBER> being the tile number the subset index described in 2.6. (see Table 1 for more information).

fv<File_Version>

File version number in the form n{1,}[.n{1,}] (That is 1 or more digits followed by optional . and another 1 or more digits). This version is fv05.0.

<Layer>

As each layer is provided as an individual GeoTIFF file, the code of each layer is:

- JD: layer 1, corresponding to the Julian day, or day of the year of detection of the BA.
- CL: layer 2, corresponding to the confidence level
- LC: layer 3, corresponding to the land cover

Example:

20050301-ESACCI-L3S_FIRE-BA-MODIS-AREA_3-fv05.0-JD.tif

20050301-ESACCI-L3S_FIRE-BA-MODIS-AREA_3-fv05.0.xml

2.8. Land Cover information

The land cover information was selected to provide information about the pre-fire land cover category, and for this reason the reference land cover used is the closest available product prior to the year being processed The land cover assigned to the pixel detected as burned was extracted from the LC_cci product (Kirches et al. 2013), to assure consistency with other variables within the CCI programme. As this land cover product has several versions, the following versions were used:

For the FireCCI50 products, the LC_cci v1.6.1 was used (Kirches et al. 2013), as it was the latest available product at the moment of BA algorithm processing. This product includes three epochs, and different land cover maps were used according to the year of the BA product:

- LC_cci of the period 1998-2002 (designed LC_cci 2000) for the 2001-2007 BA products.
- LC_cci of the period 2002-2007 (designed LC_cci 2005) for the 2008-2012 BA products.
- LC_cci of the period 2008-2012 (designed LC_cci 2010) for the 2013-2016 BA products.

The land cover categories included in the BA product are listed in Annex 1.

2.9. File metadata

For each BA product, an additional xml file with the same name is created. This file holds the metadata information following the ISO 19115 standard. The description of the populated fields is included in Annex 2.

3. Grid BA product

The grid product is the result of summing up burned area pixels within each cell of 0.25 degrees in a regular grid covering the whole Earth in biweekly composites. In addition to this variable, other attributes are stored in NetCDF file format: standard error of the estimations, fraction of burnable area, fraction of observed area, number of patches and the burned area for 18 land cover classes of LC_cci. Figure 3.1 shows the total BA from this product for 2016. This product is derived from the MODIS standard tiles in sinusoidal coordinates, which are reprojected to geographical cells of 0.25 d resolution. The impacts of this reprojection explains that minor differences may be found when comparing the grid and pixel product, particularly in total burned area or number of patches per grid cell.
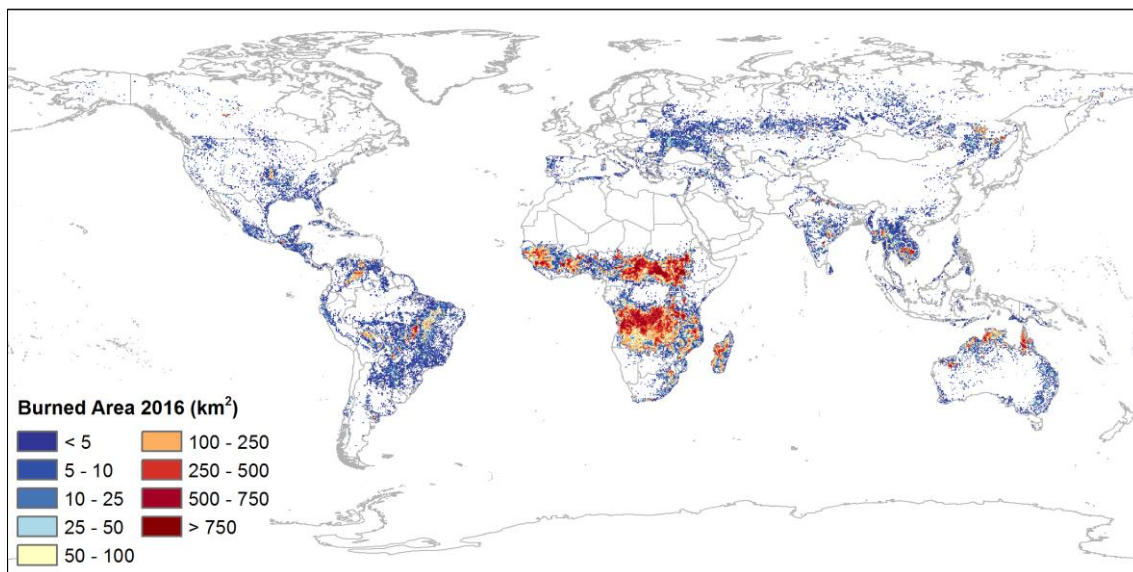
Figure 3.1: Total burned area for the year 2016.

3.1. Temporal compositing

Grid products are released at half-monthly time periods beginning at the start of each calendar month with each half being 15 days each for a 30-day month, and 15 days (the first half) and 16 days (the second half) for a 31-day month. The second half of February is either 13 days (no-leap year) or 14 days (leap year). This maintains 24 time periods with time divisions set to the convention of the calendar year.

3.2. Spatial Resolution

The spatial resolution of the grid product is 0.25 x 0.25 degrees. Grid attributes are computed from all pixels included in each cell of that size within the time period previously indicated.

3.3. Product projection system

The grid product is stored in geographical coordinates. Each cell has a latitude and longitude assignment which is tied to the centre of the grid cell. For example a series of adjacent grid cells have longitude references of -67.625°, -67.375°, -67.125° and -66.875°. Similarly a series of latitude references are 0.125°, -0.125°, -0.375° and -0.625°.

3.4. Grid attributes

The following sub-sections describe each of the grid attributes, including the name of the variables (attributes) in the NetCDF file, the unit of the attributes and the data type, and some information useful for the correct use of the product.

They also include an example of the grid product attributes.

3.4.1. Attribute 1: Sum of burned area

	Attribute	Units	Data Type	Notes
1	burned_area	Square metres	Float	Sum of area of all pixels detected as burned within each grid cell and period.

In common with other global BA products it is assumed that a pixel at the native spatial resolution of the detecting instrument was totally burned. Any burn smaller than the spatial resolution of the input sensor (for this BA product, this implies approximately 6.25 hectares) is unlikely to be detected. It can only be detected when the char signal is sufficiently different from the surroundings to alter the reflectance used in the BA detection system to a degree that triggers the detection. Further description on the methodology to obtain the burned area from the BA detections is included in the Algorithm Theoretical Basis Document (Lizundia et al. 2018).

An example of this layer corresponding to the first fortnight of August, 2016 is shown in Figure 3.2.
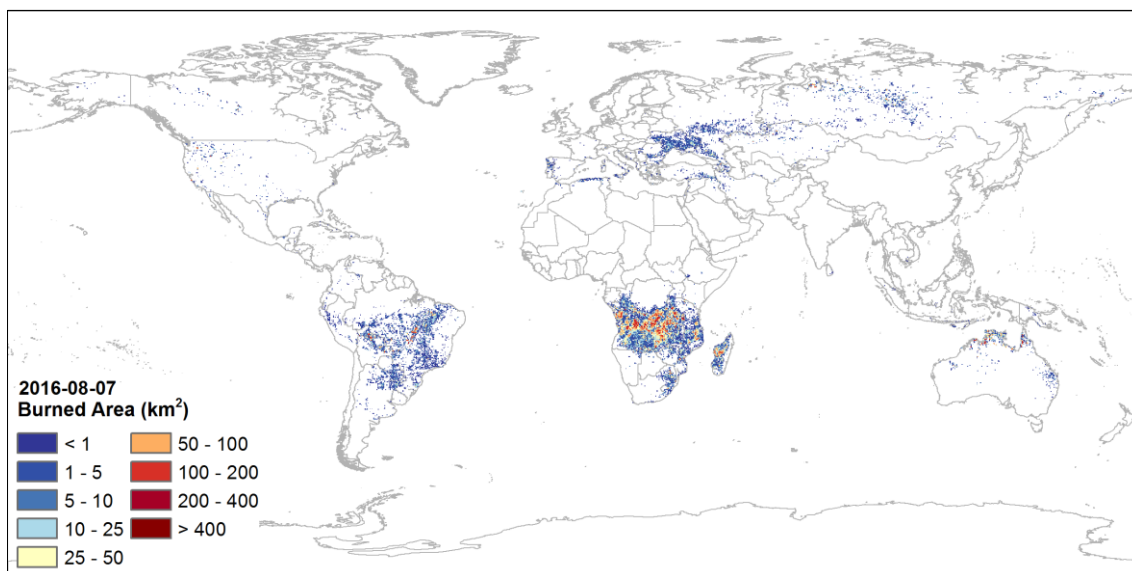

Figure 3.2: Example of the Burned Area attribute of the 20160807-ESACCI-L4_FIRE-BA-MODIS-fv05.0.nc file.

3.4.2. Attribute 2: Standard error

	Attribute	Units	Data Type	Notes
2	standard_error	Square metres	Float	This value is the standard error of the estimation of BA in each grid cell, based on the aggregation of the confidence level of the pixel product.

The standard error is modelled from the confidence level (p_b) of the pixel product. The rationale of the calculation is the following: the aggregation of the burned pixels into the grid cells implies adding up the area of each pixel. But that does not take into account that some pixels appear very clearly burned (high p_b), whereas others have lower p_b values. Some pixels have intermediate values which, in case a certain p_b threshold was used to determine a pixel being burned or not, could imply its belonging to either class if only e.g. the noise in the observations was marginally different, so the sum of burned pixels would be variable if only the input data had slightly different noise added to it. Clearly, if all pixels are either burned or unburned with very strong evidence (p_b equal to 1 or 0, respectively), then small changes in the data would not really change the aggregation, but if there are a lot of "not sure pixels" (where the data is insufficient to make a very clear distinction), this could have a major impact.

This spread of possible values is what is quantified by the uncertainty. If BAr was defined as a random variable of the number of burned pixels within a grid cell, and for simplicity it could be assumed that BAr is normal with a mean and standard deviation, an epistemic view on probability suggests that the distribution of BAr describes the strength of belief in the value of BAr lying in a particular "bin". So the belief would be maximum at the mean of the distribution of BAr, but will be very weak say 3 standard deviations away from the mean. So in this case, the standard deviation of the distribution gives a way to calculate the interval where the true mean might be based on the observed data and choice of algorithm. Note that in this case the standard deviation is saying nothing about how precisely the mean can be estimated, as the information is really contained in the shape of the distribution. Uncertainty in the case described earlier informs the user about the sensitivity of the data to the observed fire phenomenon, the ability of the algorithm and the quality of the observations that have been used to label pixels (Lewis et al. 2017).

Since the Attribute 1 was calculated as the sum of the individual burned pixel areas and not directly as BAr, the p_b was rescaled so that the mean was made equal to the sum of burned area of Attribute 1. The standard error was then computed as the standard deviation of the distribution times the pixel area in m^2 (which was a fixed size as the calculation was performed in the native sinusoidal projection). More detail on the statistical models can be found in the ATBD (Lizundia et al. 2018).

Important note: Since the pixel p_b was used for the aggregation, and it was calculated using monthly-aggregated data, it is not possible to calculate fortnight p_b or standard errors. For this reason, the values of the standard error are calculated on a monthly basis, and the same value is used for both fortnights within each month.

An example of this layer corresponding to the first fortnight of August 2016 is shown in Figure 3.3.
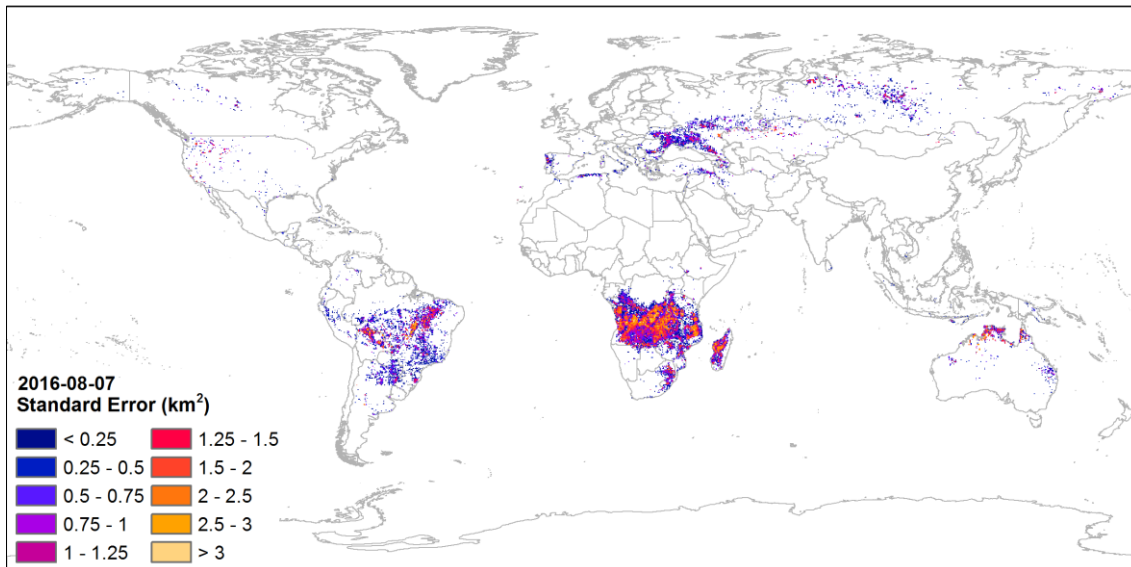
Figure 3.3: Example of the Standard Error attribute of the 20160807-ESACCI-L4_FIRE-BA-MODIS-fv05.0.nc file

3.4.3. Attribute 3: Fraction of burnable area

	Attribute	Units	Data Type	Notes
3	Fraction of burnable area	0 to 100	Float	The fraction of area in the grid that corresponds to land covers that could be affected by fire.

Includes all land cover categories that can be burned. That means that it excludes water bodies, permanent snow and ice, urban areas and bare areas. Land cover information was extracted from the LC_cci project (see section 2.8).

An example of this layer corresponding to the first fortnight of August 2016 is shown in Figure 3.4. This layer does not change biweekly, but only when a new land cover epoch is considered (see section 2.8).
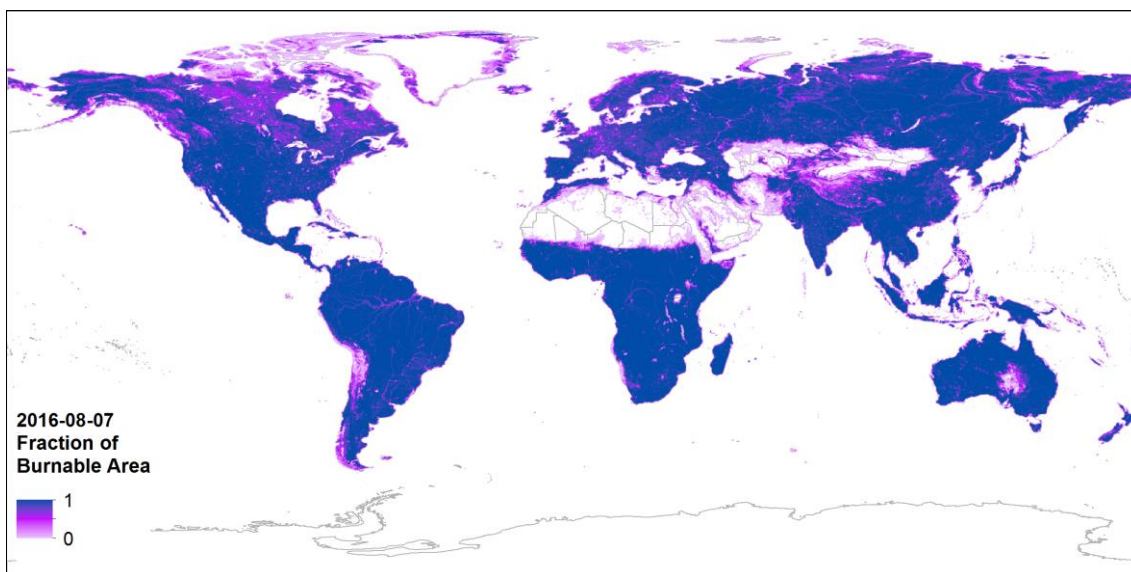

Figure 3.4: Example of the Fraction of Burnable area of the 20160807-ESACCI-L4_FIRE-BA-MODIS-fv05.0.nc file

3.4.4. Attribute 4: Fraction of observed area

	Attribute	Units	Data Type	Notes
4	Fraction of observed area	0 to 100	Float	The fraction of the total burnable area in the grid that was observed for the whole 15-day period (without cloud cover / haze or low quality pixels)

The observed area fraction is included as a layer in the grid product with the particular aim of providing information on the incomplete observation of the Earth surface by the input sensor. This may be caused by a sensor failure or by persistent cloud coverage.

Recommendation on product use: this is a very important attribute to consider, as it shows the proportion of each cell that was not observed in a particular biweekly product and therefore it identifies the regions where the product may miss burned pixels. All grid cells with fraction of observed area lower than 80% should be used with care.

An example of this layer corresponding to the first fortnight of August 2016 is shown in Figure 3.5. Please note the absence of input data for various tiles in India and equatorial Africa, for example.
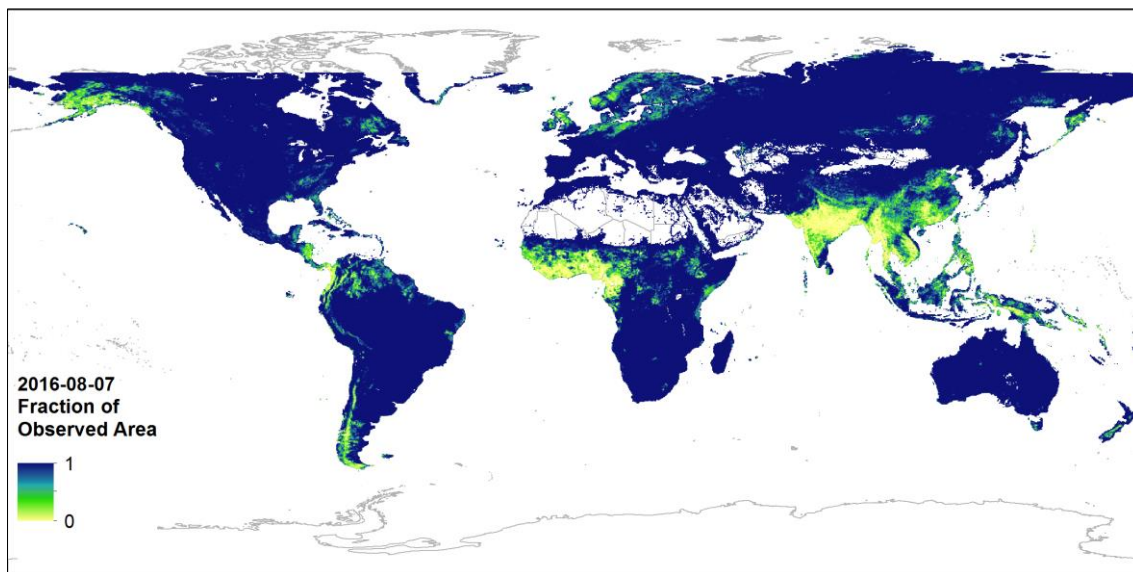
Figure 3.5: Example of the Observed Area Fraction attribute of the 20160807-ESACCI-L4_FIRE-BA-MODIS-fv05.0.nc file.

3.4.5. Attribute 5: Number of patches

	Attribute	Units	Data Type	Notes
5	number_of_patches	0 to N	Float	Number of contiguous groups of burned pixels. Contiguity is defined as any burned pixel that has contact with the side of another burned pixel during a 15 day period.

The patches were calculated in the native sinusoidal projection of the burned area product. Individual patches only contain contiguous pixels. However, when a single burn patch covers two adjacent grid cells it is considered as two separate burns. This should only marginally affect the analysis of burn patch sizes. On the opposite side, different burned areas may be considered as a single patch when they occurred around

the same dates and form together a single-continuous patch. This temporal window has been fixed to a 15-day period following experience from previous studies (Archibald et al. 2013; Hantson et al. 2015a; Hantson et al. 2015b).

In spite of these limitations (common to most other global BA products), this information is still very useful to obtain standard indicators of fire activity. To our knowledge, this information on the number of fire patches is not currently available in other standard BA products.

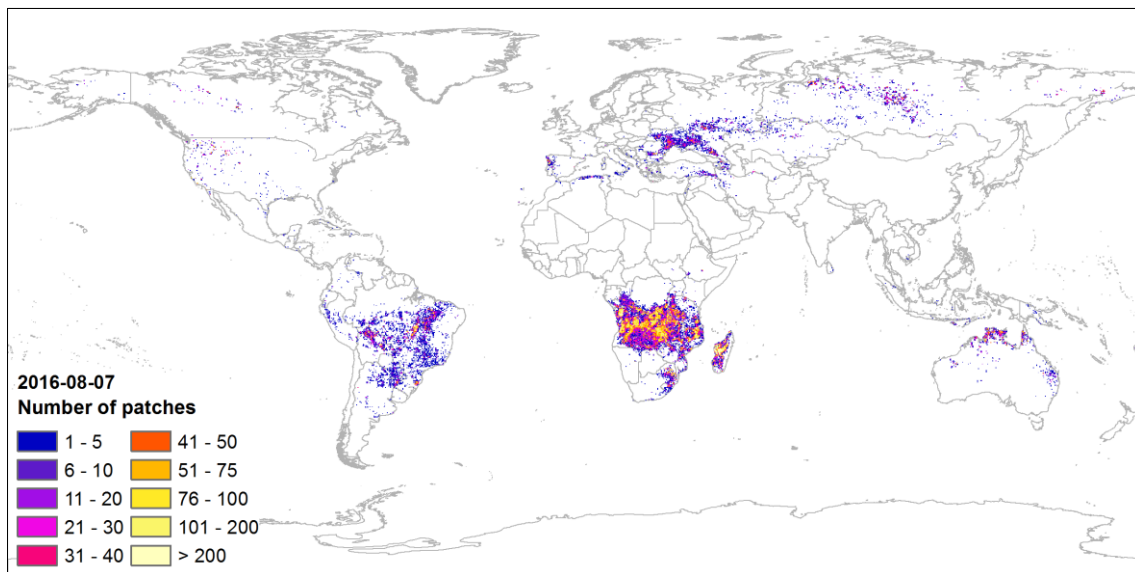An example of this layer corresponding to the first fortnight of August 2016 is shown in Figure 3.6.

Figure 3.6: Example of the Number of Patches attribute of the 20160807-ESACCI-L4_FIRE-BA-MODIS-fv05.0.nc file

3.4.6. Attributes 6-23: Sum of burned area for each land cover category

	Attribute	Units	Data Type	Notes
6 to 23	burned_area_in_vegetation_class*	Square metres	Float	Sum of all burned pixels of each land cover as defined by the LC_cci[**].

*The vegetation_class categories are those described in Annex 1.

[**] Reference land cover will be LC_cci 2000 for the 2002-2007 period, and LC_cci 2005 for the 2008-2012 period. See Section 2.8 for further information.

As in the case of the pixel product, it is assumed that each burned pixel that adds to the total burned area in a grid cell corresponds to only one land cover, as in most land cover maps. This is a reasonable estimation for homogenous land cover areas, but it may imply errors for heterogeneous landscapes. The basic land cover map is the Land Cover CCI (see Section 2.8). Obviously, the errors of this map affect the estimation provided by the Fire_cci product.

It is assumed that the land cover source has accurately described the land cover type and is spatially consistent. We aim to provide readily available information for users on the type of vegetation that has burned. This information could be used, for example, with the vegetation type dependent fuel load data for calculation of the carbon emissions and other trace gas emissions in fires, or could be used to apply vegetation type relevant combustion completeness and emission factor information in climate modelling research.

Two examples of these types of layers corresponding to the first fortnight of August 2016 are shown in the following figures. Figure 3.7 shows the sum of the burned area of croplands (LC_cci class 10), while Figure 3.8 shows the sum of BA in broadleaf deciduous trees (LC_cci class 60) for the same time period.
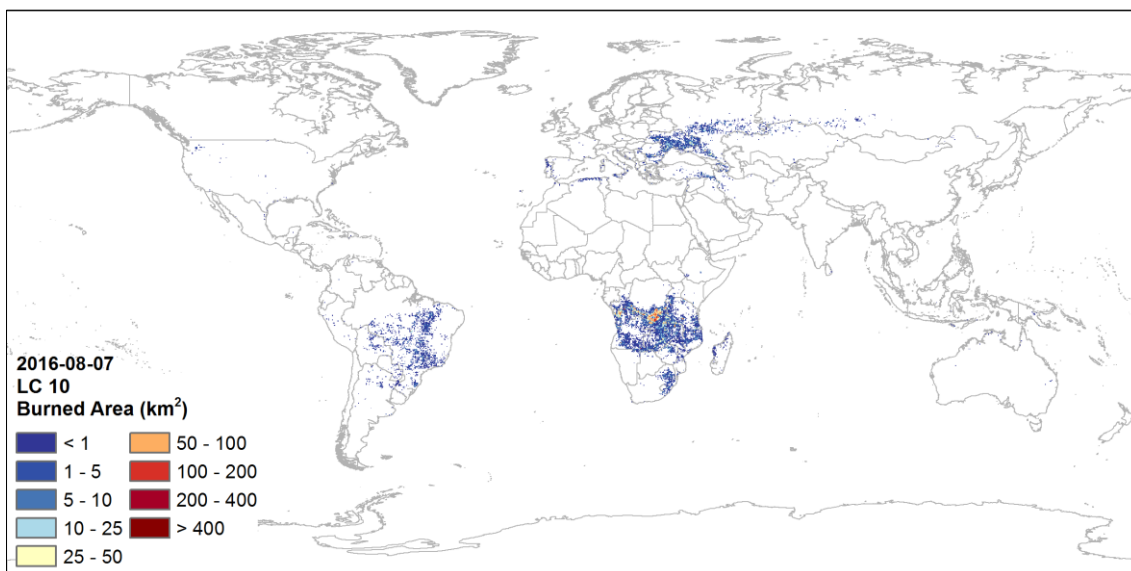
Figure 3.7: Example of the Burned Area in Vegetation Class attribute, for land cover class 10, corresponding to croplands, of the 20160807-ESACCI-L4_FIRE-BA-MODIS-fv05.0.nc file

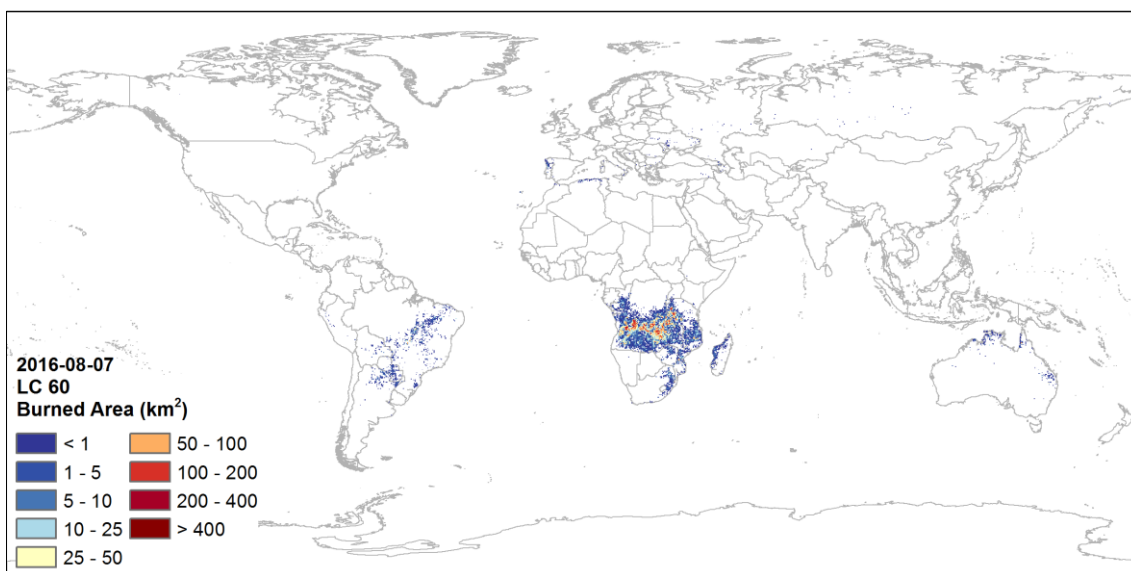**Figure 3.8: Example of the Burned Area in Vegetation Class attribute, for land cover class 60, corresponding to broadleaved deciduous tree cover, of the 20160807-ESACCI-L4_FIRE-BA-MODIS-fv05.0.nc file**

3.5. File formats

The product is delivered in raster format, on a regular geographical grid. The product format is NetCDF-CF (see http://www.unidata.ucar.edu/software/netcdf/docs for detailed information about this format).

3.6. Product file naming conventions

The grid files are named as following:

<Indicative_Date>-ESACCI-L4_FIRE-BA-<Indicative_sensor>-fv<xx.x>.nc

<Indicative_Date>

The identifying date for this data set:

Format is YYYYMMDD, where YYYY is the four digit year, MM is the two digit month from 01 to 12 and DD is the two digit day of the month from 01 to 31. For 15-day products, the first half of the month has date = 07 and the second half date = 22, which are approximately the average dates of each biweekly period.

<Indicative_sensor>

In this version of the product it is MODIS.

fv<File_version>

Version number of the Fire_cci BA algorithm. It is in the form n{1,}[.n{1,}] (That is 1 or more digits followed by optional . and another 1 or more digits.). Current version is fv05.0.

Example:

20051207-ESACCI-L4_FIRE-BA-MODIS-fv05.0.nc

3.7. File metadata

The grid files follow the NetCDF Climate and Forecast (CF) Metadata Convention (http://cfconventions.org/). Annex 3 describes the fields included in the .nc files.

4. Product validation

The final products generated in the Fire_cci project have been validated at global scale using a probability sampling design that takes into account both the spatial and temporal dimension (Padilla et al. 2017). The validation dataset was derived from multitemporal pairs of Landsat TM-ETM-OLI images selected from 2003 to 2014. The validation was based on cross tabulated error matrices, from which accuracy measures were computed to satisfy criteria specified by end-users of BA products. Accuracy differences with Fire_cci v4.1 and the NASA MCD64A1 c6 products were evaluated between each pair of products, following the theory of the stratified combined ratio estimator (Padilla et al. 2015).

Average DC values (an integrated measure of user and producer's accuracy) was found for the FireCCI50 product significantly higher than the MERIS Fire_cci v4_1 product (FireCCI41), although lower than the MCD64 one, with average values close to 0.4. Global average omission and commission errors are also lower than the previous version of the Fire_cci product, with 0.7 omission and 0.5 commission error. These values are better than the previous version of the Fire_cci product, but still worse than for the MCD64. However, error bias is lower than the one observed for the NASA product (Figure 4.1).

**Figure 4.1: Average and standard errors of validation metrics for the
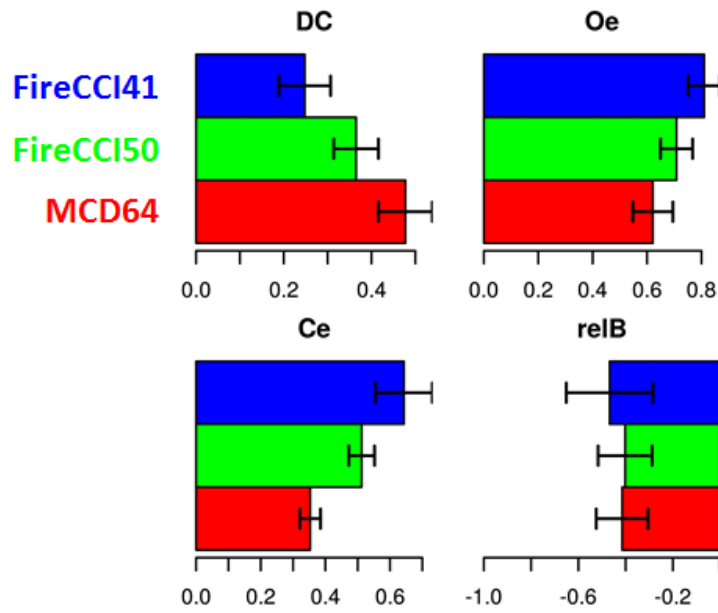Fire_cci and MCD64 BA products**

Errors were found quite stable in time, without significant time differences in both the accuracy metrics and the omission and commission errors (Figure 4.2).
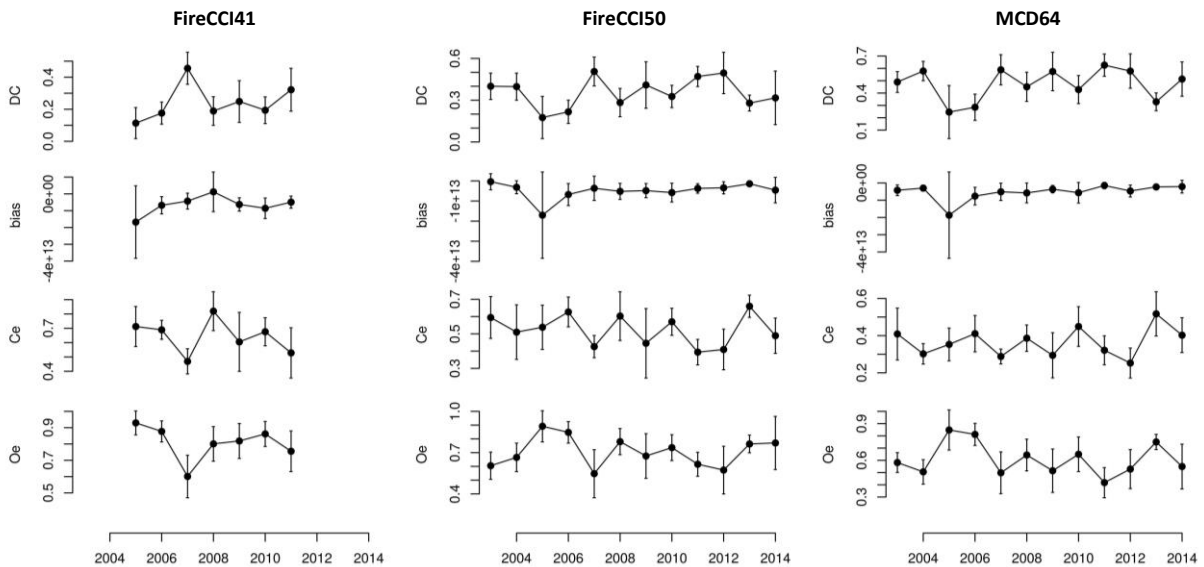

Figure 4.2: Temporal variation of accuracy metrics

Additional information on the spatial distribution of errors will be included in the Product Validation Report.

5. Data dissemination

The MODIS Fire_cci BA products are available to the public through the Fire_cci website https://www.esa-fire-cci.org/, or the CCI Open Data Portal: http://cci.esa.int/data.

We strongly recommend registering before downloading the products using the link https://geogra.uah.es/fire_cci/ (or at least sending us an e-mail to mlucrecia.pettinari@uah.es with your contact information), to contact users when new versions of the products become available.

6. Known issues

Due to the lack of MODIS images between 2001-06-16 and 2001-07-02, there is no available burned area information for the second fortnight of June 2001, and for that reason the file 20010622-ESACCI-L4_FIRE-BA-MODIS-fv05.0.nc is not included in the FireCCI50 product time series.

7. References

Archibald S., Lehmann C. E. R., L. G.-D. J. and A. B. R. (2013). "Defining pyromes and global syndromes of fire regimes." Proceedings of the National Academy of Sciences **110**(16): 6442-6447 DOI: 10.1073/pnas.1211466110.

Chuvieco E., Yue C., Heil A., Mouillot F., Alonso-Canas I., Padilla M., Pereira J. M., Oom D. and Tansey K. (2016). "A new global burned area product for climate assessment of fire impacts." Global Ecology and Biogeography **25**(5): 619-629 DOI: 10.1111/geb.12440.

Giglio L. (2015). "MODIS Collection 6 Actif Fire Product User's Guide - revision A." Department of Geographical Sciences, University of Maryland. Available at http://modis-fire.umd.edu/files/MODIS_C6_Fire_User_Guide_A.pdf.

Hantson S., Lasslop G., Kloster S. and Chuvieco E. (2015a). "Anthropogenic effects on global mean fire size." International Journal of Wildland Fire **24**(5): 589-596 DOI: http://dx.doi.org/10.1071/WF14208.

Hantson S., Pueyo S. and Chuvieco E. (2015b). "Global fire size distribution is driven by human impact and climate." Global Ecology and Biogeography **24**(1): 77-86 DOI: 10.1111/geb.12246.

Kirches G., Krueger O., Boettcher M., Bontemps S., Lamarche C., Verheggen A., Lembrée C., Radoux J. and Defourny P. (2013). "Land Cover CCI: Algorithm Theoretical Basis Document Version 2." Land_Cover_CCI_ATBDv2_2.3. Louvain, Belgium, 191 pp. Available at http://www.esa-landcover-cci.org/?q=documents#.

Lewis P., Gómez-Dans J., Brennan J. and Chernetskiy M. (2017). "Uncertainty tracking when aggregating from fine to coarse resolution in the ESA CCI Fire Product." Fire_cci. 36 pp.

Lizundia J., Pettinari M. L. and Chuvieco E. (2018). "ESA CCI ECV Fire Disturbance: Algorithm Theoretical Basis Document-MODIS, version 1.0." Fire_cci_D2.1.3_ATBD-MODIS_v1.0. University of Alcala. Available at http://www.esa-fire-cci.org/documents.

Padilla M., Olofsson P., Stehman S. V., Tansey K. and Chuvieco E. (2017). "Stratification and sample allocation for reference burned area data." Remote Sensing of Environment **203**(Supplement C): 240-255 DOI: https://doi.org/10.1016/j.rse.2017.06.041.

Padilla M., Stehman S. V., Ramo R., Corti D., Hantson S., Oliva P., Alonso-Canas I., Bradley A. V., Tansey K., Mota B., Pereira J. M. and Chuvieco E. (2015). "Comparing the Accuracies of Remote Sensing Global Burned Area Products using Stratified Random Sampling and Estimation." Remote Sensing of Environment **160**: 114-121 DOI: 10.1016/j.rse.2015.01.005.

Vermote E. F., Roger J. C. and Ray J. P. (2015). "MODIS Surface Reflectance User's Guide Collection 6." Version 1.4. MODIS Land Surface Reflectance Science Computing Facility. Available at http://modis-sr.ltdri.org/guide/MOD09_UserGuide_v1.4.pdf.

Annex 1: Land cover categories (extracted from LC_cci)

LC number	Class name	Fire_cci number
0	No data	0
10	Cropland, rainfed	10
11	*Herbaceous cover*	*10*
12	*Tree or shrub cover*	*10*
20	Cropland, irrigated or post-flooding	20
30	Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous cover) (<50%)	30
40	Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%) / cropland (<50%)	40
50	Tree cover, broadleaved, evergreen, closed to open (>15%)	50
60	Tree cover, broadleaved, deciduous, closed to open (>15%)	60
61	*Tree cover, broadleaved, deciduous, closed (>40%)*	*60*
62	*Tree cover, broadleaved, deciduous, open (15-40%)*	*60*
70	Tree cover, needleleaved, evergreen, closed to open (>15%)	70
71	*Tree cover, needleleaved, evergreen, closed (>40%)*	*70*
72	*Tree cover, needleleaved, evergreen, open (15-40%)*	*70*
80	Tree cover, needleleaved, deciduous, closed to open (>15%)	80
81	*Tree cover, needleleaved, deciduous, closed (>40%)*	*80*
82	*Tree cover, needleleaved, deciduous, open (15-40%)*	*80*
90	Tree cover, mixed leaf type (broadleaved and needleleaved)	90
100	Mosaic tree and shrub (>50%) / herbaceous cover (<50%)	100
110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	110
120	Shrubland	120
121	*Shrubland evergreen*	*120*
122	*Shrubland deciduous*	*120*
130	Grassland	130
140	Lichens and mosses	140
150	Sparse vegetation (tree, shrub, herbaceous cover) (<15%)	150
152	*Sparse shrub (<15%)*	*150*
153	*Sparse herbaceous cover (<15%)*	*150*
160	Tree cover, flooded, fresh or brackish water	160
170	Tree cover, flooded, saline water	170
180	Shrub or herbaceous cover, flooded, fresh/saline/brackish water	180

Note: Only the level 1 classes are considered, so the subdivisions have the number of broader categories. Only vegetated LC classes have been considered.

Annex 2: Metadata of the pixel product (XML file)

In each XML file corresponding to the pixel product, the following fields are populated:

- Universal Unique Identifier
- Language
- Contact
- Date stamp
- Metadata Standard Name
- Reference System
- Citation
  - Title
  - Creation date
  - Publication date
  - DOI
  - Abstract (contains information about each layer)
- Point of Contact
  - Resource provider
  - Distributor
  - Principal investigator
  - Processor
- Keywords
- Resource constraints
- Spatial resolution
- Extent:
  - Geographical extent
  - Temporal extent

Annex 3: Dimensions, variables and metadata of the gridded BA product (NetCDF file)

Here is an example of the dimensions and variables of the gridded product for the 2006-03-07 12:00:00 file:

Global Attributes:
title = 'Fire_cci Gridded MODIS Burned Area product'
institution = 'University of Alcala'
source = 'MODIS MOD09GQ Collection 6, MOD MOD09GA Collection 6, MODIS MCD14ML Collection 6, ESA CCI Land Cover dataset v1.6.1'
history = 'Created on 2017-09-28 14:35:46'
references = 'See www.esa-fire-cci.org'
tracking_id = 'b3db5a37-1623-446b-b102-d03a90430009'
Conventions = 'CF-1.6'
product_version = 'v5.0'
summary = 'The grid product is the result of summing up burned area pixels and their attributes, as extracted from their original sinusoidal projection, within each cell of 0.25 degrees in a regular grid covering the whole Earth in biweekly composites. The attributes stored are sum of burned area, standard error, fraction of burnable area, fraction of observed area, number of patches and the burned area for 18 land cover classes of Land Cover CCI.'
keywords = 'Burned Area, Fire Disturbance, Climate Change, ESA, GCOS'
id = '20060307-ESACCI-L4_FIRE-BA-MODIS-fv5.0.nc'
naming_authority = 'org.esa-fire-cci'
doi = '10.5285/f1c9c7aa210d4564bd61ed1a81d51130'
keywords_vocabulary = 'none'
cdm_data_type = 'Grid'
comment = 'These data were produced as part of the ESA Fire_cci programme.'
date_created = '20170928T143546Z'
creator_name = 'University of Alcala'
creator_url = 'www.esa-fire-cci.org'
creator_email = 'emilio.chuvieco@uah.es'
 project = 'Climate Change Initiative - European Space Agency'
geospatial_lat_min = '-90'
geospatial_lat_max = '90'
geospatial_lon_min = '-180'
geospatial_lon_max = '180'
geospatial_vertical_min = '0'
geospatial_vertical_max = '0'
time_coverage_start = '20060301T000000Z'
time_coverage_end = '20060315T235959Z'
time_coverage_duration = 'P15D'
time_coverage_resolution = 'P15D'
standard_name_vocabulary = 'NetCDF Climate and Forecast (CF) Metadata Convention'
licence = 'ESA CCI Data Policy: free and open access'
platform = 'Terra'
sensor = 'MODIS'
spatial_resolution = '0.25 degrees'
geospatial_lon_units = 'degrees_east'

geospatial_lat_units = 'degrees_north'
geospatial_lon_resolution = '0.25'
geospatial_lat_resolution = '0.25'

Dimensions:
vegetation_class = 18
lat = 720
lon = 1440
nv = 2
strlen = 150
time = 1   (UNLIMITED)

Variables:
  lat
      Size: 720x1
      Dimensions: lat
      Datatype: single
      Attributes:
            units = 'degree_north'
            standard_name = 'latitude'
            long_name = 'latitude'
            bounds = 'lat_bnds'
  lat_bnds
      Size: 2x720
      Dimensions: nv,lat
      Datatype: single
  lon
      Size: 1440x1
      Dimensions: lon
      Datatype: single
      Attributes:
            units = 'degree_east'
            standard_name = 'longitude'
            long_name = 'longitude'
            bounds = 'lon_bnds'
  lon_bnds
      Size: 2x1440
      Dimensions: nv,lon
      Datatype: single
  time
      Size: 1x1
      Dimensions: time
      Datatype: double
      Attributes:
            units = 'days since 1970-01-01 00:00:00'
            standard_name = 'time'
            long_name = 'time'
            bounds = 'time_bnds'
            calendar = 'standard'
  time_bnds
      Size: 2x1

Dimensions: nv,time
Datatype: single
vegetation_class
    Size: 18x1
    Dimensions: vegetation_class
    Datatype: int32
    Attributes:
        units = '1'
        long_name = 'vegetation class number'
vegetation_class_name
    Size: 150x18
    Dimensions: strlen,vegetation_class
    Datatype: char
    Attributes:
        units = '1'
        long_name = 'vegetation class name'
burned_area
    Size: 1440x720x1
    Dimensions: lon,lat,time
    Datatype: single
    Attributes:
        units = 'm2'
        standard_name = 'burned_area'
        long_name = 'total burned_area'
        cell_methods = 'time: sum'
standard_error
    Size: 1440x720x1
    Dimensions: lon,lat,time
    Datatype: single
    Attributes:
        units = 'm2'
        long_name = 'standard error of the estimation of burned area'
fraction_of_burnable_area
    Size: 1440x720x1
    Dimensions: lon,lat,time
    Datatype: single
    Attributes:
        units = '1'
        long_name = 'fraction of burnable area'
     comment = 'The fraction of burnable area is the fraction of the cell that corresponds to vegetated land covers that could burn. The land cover classes are those from CCI Land Cover, http://www.esa-landcover-cci.org/'
fraction_of_observed_area
    Size: 1440x720x1
    Dimensions: lon,lat,time
    Datatype: single
    Attributes:
        units = '1'
        long_name = 'fraction of observed area'

comment = 'The fraction of the total burnable area in the cell (fraction_of_burnable_area variable of this file) that was observed during the time interval, and was not marked as unsuitable/not observable. The latter refers to the area where it was not possible to obtain observational burned area information for the whole time interval because of lack of input data (non existing images for that location and period), cloud cover, haze or pixels that fell below the quality thresholds of the algorithm.'

number_of_patches

    Size: 1440x720x1

    Dimensions: lon,lat,time

    Datatype: single

    Attributes:

        units = '1'

        long_name = 'number of burn patches'

        comment = 'Number of contiguous groups of burned pixels.'

burned_area_in_vegetation_class

    Size: 1440x720x18x1

    Dimensions: lon,lat,vegetation_class,time

    Datatype: single

    Attributes:

        units = 'm2'

        long_name = 'burned area in vegetation class'

        cell_methods = 'time: sum'

        comment = 'Burned area by land cover classes; land cover classes are from CCI Land Cover, http://www.esa-landcover-cci.org/'

burnable_area_fraction

    Size: 1440x720x1

    Dimensions: lon,lat,time

    Datatype: single

    Attributes:

        units = '1'

        long_name = 'fraction of burnable area'

        comment = 'The fraction of burnable area is the fraction of the cell that corresponds to vegetated land covers that could burn. The land cover classes are those from CCI Land Cover, http://www.esa-landcover-cci.org/'

Annex 4: Acronyms and abbreviations

ATBD	Algorithm Theoretical Basis Document
BA	Burned Area
CCI	Climate Change Initiative
LC_cci	CCI Land Cover project
CE	Commission Error
CF	Climate and Forecast Metadata Convention
CRS	Coordinate Reference System
ECV	Essential Climate Variables
ESA	European Space Agency
GCS	Geographic Coordinate System
GEMI	Global Environmental Monitoring Index
LC	Land Cover
MCD64	MODIS Burned Area product
MERIS	Medium Resolution Imaging Spectrometer
MODIS	Moderate Resolution Imaging Spectrometer
NetCDF	NETwork Common Data Format
NIR	Near Infrared
OE	Omission Error
p_b	Per pixel uncertainty