ESA Climate Change Initiative – Fire_cci
D1.2 Algorithm Development Plan (ADP)

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Summary

This Algorithm Development Plan (ADP) describes the way in which the Fire_cci algorithms will be developed, as well as the specifications of the derived products.

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			References	References updated

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1 Executive Summary

This document is the Fire_cci Algorithm Development Plan (ADP) corresponding to the indicators to carry out the different versions of the BA algorithms, following the Fire_cci technical proposal and the user requirements analysis. Following the new version of the URD (URD v6.0, Heil 2019), this document also includes the main updates in product specifications from the last version of the PSD (Product Specification Document).

2 Introduction

The ESA CCI initiative stresses the importance of providing a higher scientific visibility to data acquired by ESA sensors, especially in the context of the IPCC reports. This implies to produce consistent time series of accurate Essential Climate Variables (ECV) products, which can be used by the climate, atmospheric and ecosystem scientists for their modelling efforts. The importance of keeping long-term observations, along with consistent multi-sensor with uncertainty characterisation, and the international links with other agencies currently generating ECV data is also stressed.

The fire disturbance ECV identifies burned area (BA) as the primary fire variable. Accordingly, the Fire_cci project shall focus on developing and validating algorithms to meet GCOS ECV requirements for (consistent, stable, uncertainty-characterised) global satellite data products from multi-sensor data archives (GCOS 2016).

In order to generate a long and consistent time series of BA products, which can be used by scientists for their modelling efforts, it is necessary to develop BA algorithms that are able to cope with the changes in sensor design and platform characteristics, including developing products for more than one sensor.

3 Proposed Algorithm development phases

3.1 Coarse resolution BA algorithms

3.1.1 MODIS VNIR

No updates of this algorithm are expected during the Fire_cci+ project. As described in the technical proposal, the latest version of this algorithm –used to generate the FireCCI51 (Lizundia-Loiola et al. 2018) will be adapted to the characteristics of the SYN product.

3.1.2 Sentinel-3 SYN

The BA algorithm will be based on the one developed for processing the MODIS 250m resolution bands. This algorithm is patch-based and provides contextual analysis to adapt thresholds to the local characteristics of burned areas. It only requires active fire information and near-infrared (NIR) reflectance. Since the algorithm offers a high adaptability, the idea is to analyse first how the new inputs affect its results, without changing the main structure. It is necessary to understand those effects to be able to provide improvements. Once SYN data are available, the following development tests are envisaged:

1. Analyse the most convenient band for BA thresholding. A separability analysis will be carried out, from a statistical sample of burned and unburned pixels. Different inter-class measurements will be used to identify the most sensitive band for discriminating burned and unburned pixels. General discrimination power, as well as ecosystems and land cover discrimination will be tested.

2. The impact of using more than one thresholding band will be tested, including different spectral indices using both NIR and SWIR information. Since SYN data include 21 bands, a wide variety of spectral indices can be used to better discriminate burned and unburned pixels. Similarly to 1, a separability analysis will be conducted to determine the most suitable one. Well-known indices previously used in BA detection, such as the NBR and MIRBI, will be tested.
3. Temporal compositing is a critical step in our algorithm, as it reduces commission errors caused by sensor noise and cloud contamination. The last version of the algorithm uses a minimizing criterion to select the most suitable date, but it can be easily changed by a maximizing criterion. Therefore, the most separable bands and indices given by the steps 1 and 2 can be integrated in the algorithm to produce new composites to analyse their performance. Besides, this will help to check the ability of each band or index to better preserve the closest post-fire pixel of the time series.
4. A better characterization of uncertainty will be carried out. In the previous version the uncertainty was given as a probability of burned derived from a logistic regression. Although this first approach helped us to understand how each variable affect the final uncertainty, it was not enough to analyse how the errors were propagated throughout the algorithm. Since a step-by-step mathematical error propagation is not feasible in algorithms that rely on thresholding processes (Merchant et al., 2017) we propose to apply Monte Carlo simulations limiting the input variability using the uncertainty provided by the input data.
5. In the previous phase MODIS active fire information was used as input for the FireCCI50 and FireCCI51 products. However, the current life expectancy of Terra and Aqua is estimated to be 2020 and early 2020s, respectively. So we propose to change the active fire information source to VIIRS on board Suomi-NPP and NOAA-20, considering that a SLSTR active fire product is still not available. The overlapping year (2019 due to the availability of SYN data) will be used to see the impact of changing this sensor. The latter offers active fire information at 375 m, while MODIS offers at 1000 m. This means a potential increase in the detection of small fires that could be undetectable in our current spatial resolution. Hence, a stricter active fire filtering is proposed based on the clustering approach used in the previous version.
6. Once we understand the impacts of the previous changes, the idea is to improve the thresholding approach changing, if necessary, how the unburned and burned samples are selected and combined. Currently the sampling is made in the burned case using the active fires and in the unburned case using those pixels that are at some specific distance from the active fires. It is necessary to assess if the distances proposed for MODIS (250m) continue being the most suitable ones for SYN (300m). Besides, the mathematical expression that combines median and mode of the burned and unburned sample, respectively, will be evaluated as well.

3.1.3 LTDR

The Fire_cci+ project will continue improving the LTDR algorithm developed for Option 2 of the Fire_cci Phase 2 (Otón et al. 2019). The following tests will be carried out:

1. The whole time series will be reprocessed if new versions of the LTDR dataset are released by NASA. Complementary, the AVHRR record generated by SST_cci will also be considered and evaluated.
2. Test the impact of modifying the criteria to convert the classification outputs of the Random Forest (RF) classifier (Breiman 2001) to total burned area. For Fire_cci

Phase 2, it was based on the MCD64A1 product. In the new project, FireCCI51 will be used instead.

3. Convolutional Neural Network (CNN) classifiers will be tested to improve the discrimination of burned pixels.
4. Having access to active fire information will be critical to improve the detection of burned pixels, but this information is not available for the first 20 years of the LTDR series. We are collaborating with King's College London in a project they currently have to detect active fires from GAC data, so we could eventually incorporate active fire information into the LTDR product.

3.1.4 Merging of products

In this case, the merging will be done at product level, meaning that a single grid will be created from information of BA derived from the different sensors (SYN, MODIS and LTDR). The estimation will be based on:

1. Singe regression analysis.
2. Geographically weighed regression.

3.1.5 Merged reflectance

A single year (2019, due to data availability) will be selected to analyse the impacts of using different input data in the classification accuracy. The following combinations will be tested, using the same BA algorithm (the most mature from the tests previously presented for SYN):

1. SYN (from S3A&B) and MODIS data.
2. SYN (from S3A&B), MODIS and LTDR data

3.2 Medium resolution BA algorithms

3.2.1 Sentinel-2 Optical data

We will rely on developments of the Fire_cci Phase 2 project with Sentinel-2A MSI images over Africa (Roteta et al. 2019). The same algorithm will be used to generate a new BA product over Africa in 2019. The only changes from the previous processing will come from updates in the input data: L2 Sentinel-2A & B will be used instead of L1 data from only the A satellite, and the hotspots will be those of VIIRS instead of MODIS.

3.2.2 Sentinel-1 SAR algorithm

Sentinel-1 based BA detection will rely on the algorithm developed in Fire_cci 2 (Belenguer-Plomer et al. 2019a). The algorithm uses as input temporal series of C-band dual polarized (VV an VH) data and applies the Reed-Xiaoli detector (RXD) to distinguish anomalous changes of the backscatter coefficient. Such changes are related to fire events using information on thermal anomalies (hotspots) acquired during the detection period by ancillary sensors.

To improve the current algorithm, an extensive analysis, based on Belenguer-Plomer et al. (2019b) will be carried out to ascertain the utility of different SAR based indices (eq. 1-8) during the burned area detection and classification as a function of land cover class, fire severity, soil moisture, and topography (slope and aspect). Information on fire severity will be derived from optical sensors while soil moisture and topographic features will be retrieved from ancillary datasets such as the Copernicus Surface Soil Moisture and respectively the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) at 30m.

$$RI_1 = \gamma^0 VV_{t-1} / \gamma^0 VV_{t+1} \quad (1)$$
$$RI_2 = \gamma^0 VH_{t-1} / \gamma^0 VH_{t+1} \quad (2)$$
$$RI_3 = \log\left(\gamma^0 VV_{t-1} / \gamma^0 VV_{t+1}\right) \quad (3)$$
$$RI_4 = \log\left(\gamma^0 VH_{t-1} / \gamma^0 VH_{t+1}\right) \quad (4)$$
$$RI_5 = \gamma^0 VV_{t-1} - \gamma^0 VV_{t+1} \quad (5)$$
$$RI_6 = \gamma^0 VH_{t-1} - \gamma^0 VH_{t+1} \quad (6)$$
$$RI_7 = \left(\gamma^0 VH_{t-1} / \gamma^0 VV_{t-1}\right) / \left(\gamma^0 VH_{t+1} / \gamma^0 VV_{t+1}\right) \quad (7)$$
$$RI_8 = \log\left(\left(\gamma^0 VH_{t-1} / \gamma^0 VV_{t-1}\right) / \left(\gamma^0 VH_{t+1} / \gamma^0 VV_{t+1}\right)\right) \quad (8)$$

where γ^0 is the backscatter coefficient in linear scale (VV or VH polarizations), and t-1 and t+1 are pre-fire and respectively post-fire dates.

The importance of each index will be analysed through the random forests classifier (Breiman 2001). The importance of each index is computed by the random forests during the classification of burned and unburned areas. The reference burned areas will be obtained from optical sensors. Such an approach was used recently in an increasing number of studies to extract the importance of the independent variables used for the classification process (Belgiu and Dragut 2016; Nguyen et al. 2018; Hislop et al. 2019; Zhang et al. 2019. In addition, the analysis shall take into account the land cover class, topographic slope and aspect, soil moisture and fire severity due to their influence on the SAR scattering processes. The importance values shall be converted to percentages (Eq. 9) to allow for inter-comparisons between different groups.

$$\mathrm{pImp}_{RI_i} = \frac{\mathrm{Imp}_{RI_i} \times 100}{\sum_{i=1}^{8} \mathrm{Imp}_{RI_i}} \quad (9)$$

where pImp is the percentage importance of a given radar index (RI) *i*.

Further analyses will be focused on the sources of the SAR temporal decorrelation (Belenguer-Plomer et al. 2018). Several variables influencing backscattering processes such as fire severity, vegetation growth and water content, surface soil moisture, and the local slope and aspect will be analysed to evaluate their influence on the temporal decorrelation between fire occurrence and the change in SAR signal. As in the previous case optical sensors or ancillary products shall be used to derive or retrieve the mentioned variables and random forests will be employed to ascertain their importance.

The gained knowledge will allow improving the current algorithm. In addition, the improved algorithm will allow for a better characterization of uncertainty during the different phases (e.g., SAR pre-processing, change detection and RF classification). The extent of the improvements will be tested over 18 tiles (100x100 km each) located in representative biomes. The reference datasets for these tiles are available from Fire CCI Option 3.

3.2.3 Merged S-1 and S-2 algorithm

The RXD based SAR algorithm (see Belenguer-Plomer et al. 2019) will be modified to accept as input both Sentinel-1 backscatter and Sentinel-2 reflectance data. The combined SAR-optical (SAR-O) algorithm shall work seamlessly over the entire tile by using the available information at pixel level. Cloud free pixels will be mapped using information from both sensors with the input channels` (e.g. VV backscatter, VH backscatter, NIR reflectance, temporal indices) importance being weighted depending on the land cover class. Cloud affected pixels will be mapped using SAR data and contextual information from neighbouring cloud free pixels. Uncertainty will be computed as a function of the information channels used at pixel level.

The SAR-O algorithm will be applied over three study sites (400x400 km each) characterized by different climatic conditions. Different combinations of input sensors will be tested to understand their contributions to BA detection.

1. Single Sentinel-2 MSI images
2. Single Sentinel-1 SAR images
3. Combined use of Sentinel-2 MSI and Sentinel-1 SAR

The accuracy of the products obtained through different combinations of Sentinel-1 and Sentinel-2 datasets shall be assessed through product validation (see Stroppiana and Boschetti 2019).

4 Updates of the PSD

The following sections summarize the changes applied to the new products compared to the product specifications indicated in Chuvieco et al. (2017).

4.1 Product naming convention

The Fire_cci products are identified using a long name (e.g. Fire_cci MODIS burned area product version 5.1), and a short name (for the previous case, FireCCI51). The short names were requested by the CRG to simplify referring to the products in graphs and tables, both in internal reports and in communications and peer review publications.

The naming convention adopted for the Fire_cci BA products that will be produced during this phase of the Programme are presented in Table 1.

Table 1: Fire_cci products naming convention

Name of the product	Sensor	Temporal series	Geographical coverage
FireCCISFD20	S2 A+B	2019	Sub-Saharan Africa
FireCCIS1S2AF10	S1 + S2	2019	3 study sites in Africa
FireCCILT20	AVHRR LTDR	1982-2019	Global
FireCCIS310	S3 SYN	2019	Global
FireCCIS311	S3 SYN	2019-2020	Global
FireCCIMR10	AVHRR+MODIS+SYN Reflectance	2019	Global
FireCCI60	AVHRR+MODIS+SYN BA	1982-2020	Global

4.2 Data requirements for BA products

4.2.1 Input data

In addition to the input sensors described in the latest version of the DARD (Pettinari et al. 2017), the generation of new products for Fire_cci+ will require using Sentinel-3 (S3) data. This satellite was primarily designed as an ocean mission, but it also provides very useful data for atmospheric and land applications. The first satellite of this mission (Sentinel-3A) was launched on 16 February 2016, with a second satellite (Sentinel-3 B) launched on 25 April 2018, on the same orbit but flown 140° out of phase. The orbit is sun-synchronous, with a height of 814.5 km, an inclination of 98.65° and a repeat cycle of 27 days, crossing the equator at around 10:00 am local solar time. S3 includes 7 instruments: OLCI, SLSTR, SRAL, MWR, DORIS, LRR and GNSS. For Fire_cci+ only the first two sensors will be used.

The Ocean and Land Colour Instrument (OLCI) sensor is a follow up version of ENVISAT MERIS, and it includes, amongst others, the bands that were defined for the MERIS sensor. It is a push-broom instrument with 5 camera modules sharing the FOV, each one with a FOV of 14.2° and 0.6° with its neighbours. The whole FOV is shifted across track by 12.6° away from the Sun to minimise the impact of Sun glint. It has a swath of 1270 km, and a native resolution of ~300 m, and it provides global land coverage at the equator in 2.2 days with one satellite and in 1.1 days with two satellites.

The Sea and Land Surface Temperature Radiometer (SLSTR) is a dual view (near-nadir and backward views) conical imaging radiometer aboard Sentinel-3 satellites, which provides continuity to the ENVISAT AATSR instrument. Its dual view scan has a swath width of 1420 km at nadir and 750 km backwards.

The OLCI OL_1_ERF product (https://sentinel.esa.int/web/sentinel/user-guides/ sentinel-3-olci/product-types/level-1b, last access July 2019), in conjunction with the SLSTR SL_1_RBT product (https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-slstr/data-formats/level-1, last access July 2019), provides the Synergy (SYN) products.

The SYN products distributed to the public are (all links last accessed on July 2019):

- Level-2 SYN product (SY_2_SYN): contains surface reflectance and aerosol parameters over land, provided on the OLCI image grid, similar to the OLCI Level-1B product (~300m), for the sun-reflective channels of SLSTR (both in nadir and oblique view) and for all OLCI channels except bands Oa14, Oa15 and Oa20. https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-synergy/ product-types/level-2-syn
- Level-2 VGP product (SY_2_VGP): contains TOA reflectances at 1 km spatial resolution, provided on a regular latitude-longitude grid (called 1 km VEGETATION-like product) https://sentinel.esa.int/web/sentinel/user-guides/ sentinel-3-synergy/product-types/level-2-vgp
- Level-2 VG1 product (SY_2_VG1): will contain daily synthesis of surface reflectance, with the spatial resolution of the 1 km VEGETATION-like product, based on information of same channels of SPOT-VGT (B0, B2, B3 and MIR) produced with OLCI and SLSTR data. It will also contain NDVI information. https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-synergy/product-types/level-2-vg1-v10
- Level-2 VG10 product (SY_2_VG10): similar to the VG1, but with a 10-day synthesis surface reflectances and NDVI.

SYN data is freely available, and can be downloaded from the Copernicus Open Access Hub (https://scihub.copernicus.eu/dhus/#/home, last access July 2019). SY_2_SYN data will be used as input data for the project.

4.2.2 Global Land cover map

As requested by the users, land cover information complements the information included in BA products, in addition to be used by BA algorithms to reduce commission errors and improve processing efficiency. Also as requested in the URD, our products will use the latest version of the ESA's CCI Land Cover project (LC_cci, http://www.esa-landcovercci.org/, last access July 2019), which is named LC_cci v2.0.7. This product includes annual land cover maps from 1992 to 2015 (ESA 2017). For years following 2015, the Copernicus Climate Change Service (https://climate.copernicus.eu/, last access July 2019) land cover product v2.1.1, which is the continuation of the LC_cci product, will be used. In all cases, the land cover corresponding to the year prior to the BA detection is used.

4.2.3 Active Fires

Active fire information is used in many algorithms as the first step of burn area detection, for the identification of burned seeds and dates of burn. In previous versions of the BA algorithms, MODIS active fire products (MCD14ML Collection 6) were used.

Current versions of the algorithms will also explore the use of Visible Infrared Imaging Radiometer Suite (VIIRS) active fire data at 375m spatial resolution. The VIIRS sensor is on board the Suomi National Polar-orbiting Partnership (Suomi NPP) and NOAA-20 weather satellites. It was launched on Suomi NPP on 28 October 2011, and on NOAA-20 on November 18, 2017.

This information is available since January 2012 to the present, and it is freely downloadable from https://firms.modaps.eosdis.nasa.gov/download/ (last access September 2019). The data that will be used is the “standard science quality data”, produced with a 2-3-month lag from detection, and which more stable than the Near Real Time data.

4.2.4 Reference BA information

The details of the reference data to be uses, along with the methods for the validation, are described in Stroppiana and Boschetti (2019).

4.3 Updates in Product Specifications

The same terms of reference previously used for Fire_cci products will be used in the cci+ programme. Pixel and grid products will be generated from the results of the BA algorithms. Monthly summaries will be derived from both products.

For pixel products, four layers will be generated, including (as in previous versions) the date of detection, the confidence level, the burned land cover and the Sensor detecting the BA pixel. In this latter layer, new codes will be used:

- 0 (zero): when the pixel is not burned in the month.
- 1: MODIS (on the Terra satellite)
- 2: SYN (on the Sentinel-3 satellite)
- 3: AVHRR (on the NOAA satellites)
- 4: MSI (on the Sentinel-2 satellite)
- 5: SAR (on the Sentinel-1 satellite)
- Combination of sensors will be expressed by combining the sensor codes. For instance, 45 means a pixel detected by MSI and SAR.

Pixel products will be delivered in GeoTIFF format, as requested by the users of the product. They will use the geographic coordinate system (GCS) based on the World Geodetic System 84 (WGS84) reference ellipsoid and using a Plate Carrée projection. To facilitate handling the results, the world product will be split in several tiles. Considering recent impacts of fire on Greenland, this continent has been added to the distribution of tiles (Figure 1). The new distribution is:

Table 2: Geographical distribution of BA tiles for the pixel product

Areas	Name	Upper left		Lower right	
1	North America	180°W	83°N	26°W	19°N
2	South America	105°W	19°N	34°W	57°S
3	Europe & Northern 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

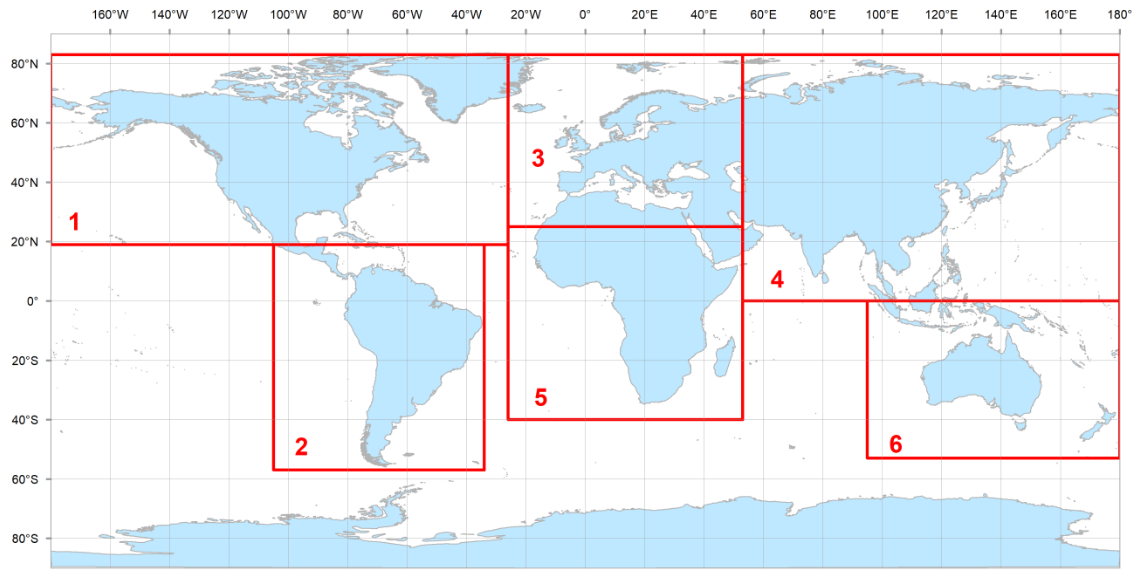

Figure 1: Geographical distribution of subsets for the global BA product

Figure 1:

The BA pixel products generated from medium-resolution sensors (S2, S1), will be delivered in geographical tiles of 5x5 degrees (see Figure 2). The tiles to be provided will cover only those corresponding to the African continent.

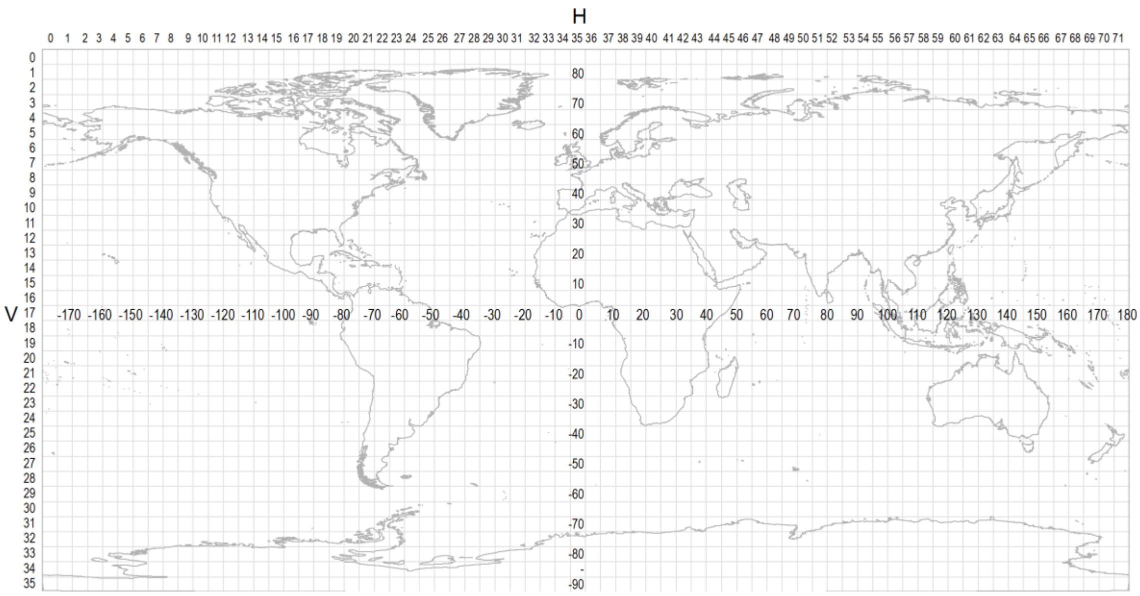

Figure 2: Geographical distribution of tiles for medium-resolution products

The grid products will be offered in NetCDF-CF format at 0.25 x 0.25 degrees of resolution, with 0.05 x 0.05 degrees for the small fire database. Grid attributes will be same as in previous versions of the BA products, with the exception of the number of burned patches layer, which will be removed, as it was not found very useful to the end users.

4.4 Data dissemination for all products

The final versions of the BA products, both in pixel and gird format, will be served through the CCI Open Data Portal FTP (ftp://anon-ftp.ceda.ac.uk/neodc/esacci/fire/, last access July 2019).

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Annex 1: Acronyms and abbreviations

AATSR	Advanced Along-Track Scanning Radiometer
ADP	Algorithm Development Plan
AVHRR	Advanced Very High Resolution Radiometer
BA	Burned Area
CCI	Climate Change Initiative
CNN	Convolutional Neural Network
CRG	Climate Research Group
CRS	Coordinate Reference System
DEM	Digital Elevation Model
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
ECV	Essential Climate Variables
ENVISAT	ENVIronmental SATellite
ERS	European Remote sensing Satellite
ESA	European Space Agency
EU	European Union
FTP	File Transfer Protocol
GAC	Global Area Coverage
GCOS	Global Climate Observing System
GCS	Geographic Coordinate System
LC	Land Cover
LC_cci	CCI Land Cover project
LRR	Laser RetroReflector
LTDR	Long Term Data Record
MERIS	Medium Resolution Imaging Spectrometer
MODIS	Moderate Resolution Imaging Spectroradiometer

MSI	MultiSpectral Instrument
MWR	MicroWave Radiometer
NASA	National Aeronautics and Space Administration's
NDVI	Normalized Difference Vegetation Index
NetCDF	NETwork Common Data Format
NIR	Near InfraRed
NPP	National Polar-orbiting Partnership
OLCI	Ocean and Land Colour Instrument on board Sentinel-3
PSD	Product Specification Document
RF	Random Forest
RI	Radar Index
RXD	Reed-Xiaoli detector
S1	Sentinel-1
S2	Sentinel-2
S3	Sentinel-3
SAR	Synthetic Aperture Radar
SAR-O	SAR-Optical
SFD	Small Fire Database
SLSTR	Sea and Land Surface Temperature Radiometer
SPOT	Satellite Pour l'Observation de la Terre
SRAL	Synthetic Aperture Radar Altimeter
SRTM	Shuttle Radar Topography Mission
SST	Soil Surface Temperatur
SYN	Synergy
WGS84	World Geodetic System 1984